IDRC 176e

Multiple Cropping in the Humid Tropics of Asia

A.A. Gomez and K.A. Gomez

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Postal Address: Box 8500, Ottawa, Canada K1G 3H9
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IDRC-176e

Multiple cropping in the humid tropics of Asia. Ottawa, Ont.,IDRC, 1983. 248 p. : ill.

/Multiple cropping/, /crop diversification/, /intercropping/, /traditional technology/, /technological change/, /agricultural research/, /tropical zone/, /Asia/ - /research and development/, /rice/, /maize/, /cowpeas/, /Philippines/, /crop yield/, /production statistics/, /statistical tables/, bibliography.

UDC: 631.58(213) ISBN: 0-88936-304-8

Microfiche edition available

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MULTIPLE CROPPING IN THE HUMID TROPICS OF ASIA

A. A. GOMEZ and K. A. GOMEZ

Résumé

La polyculture est la culture simultanée de différents produits sur un même champ. Cette pratique permet l'utilisation optimale du sol, la diversification des produits et la stabilisation des revenus annuels. Elle constitue donc, pour l'Asie où les nouvelles terres agricoles sont rares, une stratégie valable pour l'augmentation des rendements et l'absorption d'une population agricole croissante. Étant donné que la succession des cultures est rapprochée, la gestion de l'une peut grandement influencer le rendement de la suivante. Aussi, la création et la diffusion de la technologie mise au point pour la monoculture peuvent ne pas trouver d'application pratique en polyculture.

La présente brochure comprend un résumé des résultats des recherches actuelles et des efforts de développement de la polyculture dans les régions tropicales humides de l'Asie, une appréciation des écoles de pensée relatives aux méthodes de recherche et de vulgarisation, les domaines de recherche et de développement susceptibles de maximiser les profits en terme d'accroissement de la productivité agricole ainsi qu'une description de l'expérience des Philippines où les fermiers ont rapidement adopté les techniques polycoles.

Resumen

El cultivo múltiple consiste en sembrar varios cultivos en un mismo pedazo de tierra. Ello aumenta la diversidad de los productos agrícolas y la estabilidad del producido anual, al tiempo que puede intensificar el uso de la tierra. En Asia, donde la tierra agrícola se hace cada vez más escasa, el cultivo múltiple representa una estrategia valiosa para aumentar la producción y absorber la creciente población agrícola. Como la sucesión de cultivos es muy rápida en este sistema, el manejo que se le dé a uno puede influir decisivamente en el comportamiento de los que le siguen. Por ello, los procedimientos tradicionales para la generación y diseminación de tecnología, que se concentran en un cultivo a la vez, pueden no resultar apropiados para el cultivo múltiple.

Este libro reseña los resultados de los esfuerzos que se realizan hoy día para la investigación y el desarrollo de los cultivos múltiples en los trópicos humedos de Asia. Evalúa las distintas posiciones actuales sobre metodologías de investigación y estensión, identifica las áreas de investigación y desarrollo que se espera optimicen los resultados en términos de una productividad agrícola aumentada, y describe la experiencia Filipina en acelerar la adopción de las técnicas de cultivo múltiple por parte de los agricultores.

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PREFACE

Multiple cropping, or the practice of growing several crops on the same piece of land, is an ancient strategy for crop production among farmers in the tropics. Traditionally, it is used by subsistence farmers primarily to increase the diversity of their products and the stability of their annual output. However, with the rapid increase in farm population and the dwindling supply of new lands for cultivation, multiple cropping is being looked upon as an excellent strategy for intensifying land use and for absorbing excess farm labour. In the rain-fed rice paddies, for example, with the use of fast-maturing varieties and management practices that lengthen the growing season (i.e., direct seeding and zero tillage), as many as three crops per year can be grown on a piece of land where formerly only one crop of rice was grown. In the upland areas, yield per hectare can be increased 50% or more by intercropping -- the planting of several crops simultaneously in the same parcel of land.

With the intensification of land use through multiple cropping, the succession of crops is very rapid (i.e., the interval between harvesting of one crop and planting of another is short), and the management of one crop can significantly influence performance of succeeding crops. Thus, the traditional procedures for the generation and dissemination of technology, which concentrated on one crop at a time, may not be adequate for multiple cropping.

What is required for the generation of multiple-cropping technology is a procedure that is able to measure the interaction among crops grown on the same piece of land. For the dissemination of that technology, more motivation and guidance may be required by the farmers before they accept multiple-cropping techniques that generally require more resources and management capability relative to monocropping.

This book is written in recognition of the great potential of multiple cropping for increasing farm productivity in the humid tropics of Asia, and of the unique requirements, as well as the urgent need for the rapid generation and dissemination, of multiple-cropping technology. Written primarily for practicing and prospective agricultural researchers and rural development workers, the book summarizes the results of current research and development efforts in multiple cropping, evaluates contemporary schools of thought on research and extension methodologies, identifies areas of research and development that are expected to maximize payoffs in terms of increased farm productivity, and describes the Philippine experience in accelerating the adoption by farmers of multiple-cropping techniques.

The authors are grateful to the International Development Research Centre (IDRC) for its financial support to the senior author during the initial stages of writing this book, and to the University of the Philippines at Los Baños (UPLB) for allowing him to spend full time in completing the manuscript. The authors acknowledge with thanks the many colleagues who reviewed the first draft of the manuscript especially Drs R.R. Harwood, formerly multiple cropping agronomist, International Rice Research Institute (IRRI), and currently director, Organic Gardening and Farming Research Center; S.K. de Datta, agronomist, IRRI; K. Moody, weed scientist, IRRI; R.W. Herdt, agricultural economist, IRRI; Gordon Banta, agricultural economist, IDRC; and Ch. Khrisnamoorty, director, All India Coordinated Research Project for Dryland Agriculture. The authors are deeply indebted to these reviewers for their many useful suggestions.

CHAPTER 1: INTRODUCTION

The humid tropics, unlike temperate regions where the crop-growing period is limited by low temperature during the winter months, are characterized by a temperature regime that is favourable for crop production year round. In addition rainfall intensity is high and its distribution is uneven and periodic so that effective sunshine is low during the rainy months. The level of agricultural productivity in the humid tropics is greatly dependent upon these two most critical factors -- rainfall and solar energy (Wijewardene 1978). High rainfall leads to heavy erosion, leaching of nutrients, rapid loss of fertility, and rapid growth of weeds. The low level of solar energy (300 to 350 cal/cm^2/day) during the rainy months, the period in which most crops in the tropics are grown, is about half of that available to crops grown during the summer months in the temperate regions.

Average yield of a crop in the humid tropics is generally lower than that of the same crop in the temperate regions (Table 1.1). However, since the annual growing season in the tropics can be much longer than that in the temperate regions, the low yield per crop in the tropics can be offset by growing not only one crop, but as many as possible. The strategy of growing several crops in the same parcel of land is referred to as multiple cropping.

The salient features of multiple cropping will be illustrated using the rice - rice - mung bean sequential cropping pattern, which is commonly used in lowland rice paddies of the humid tropics of Asia. To lengthen the growing season, the first rice crop is usually direct-seeded soon after the first monsoon rains. The second rice crop, on the other hand, is transplanted to shorten the period during which it occupies the field. Finally, mung beans are planted immediately after, or even before, the harvest of the second rice crop, to ensure maximum use of the limited residual soil moisture. This cropping pattern illustrates the following important characteristics of multiple cropping:

a) That the component crops of a cropping pattern must be planned and implemented jointly, because the management of one component crop greatly influences the productivity of the others;
b) That the appropriate management for the same crop species may change depending upon the position of the crop in the pattern; e.g., the first rice crop is direct-seeded whereas the second rice crop is transplanted; and
c) That the management practice for a component crop in the pattern is chosen not to maximize production of that particular crop but rather to maximize production of the whole pattern; e.g., mung beans may produce more if planted on a well-prepared seed bed but, in the present cropping pattern, they are generally grown under zero tillage to conserve residual soil moisture.

Table 1.1. Average yield of some important annual crops in temperate and tropical countries of Asia

Country	Average crop yield (t/ha)						
	Rice	Corn	Soybeans	Peanuts	Sweet potatoes	Cassava	Tomatoes
Tropical							
Indonesia	2.92	1.10	0.79	1.35	7.81	9.21	6.35
Philippines	1.84	0.96	0.82	0.73	4.00	9.59	na[1]
Thailand	2.05	2.16	0.71	1.36	10.17	18.34	2.98
Average	2.27	1.41	0.77	1.15	7.33	12.38	4.66
Temperate							
China	3.53	3.00	0.92	1.17	8.60	13.90	13.55
Japan	6.25	2.75	1.50	1.79	20.00	na	51.89
Korea	6.55	3.40	1.19	1.13	19.29	na	18.57
Average	5.44	3.05	1.20	1.36	15.96	13.90	28.00

[1] Data not available.

Source: FAO (1979).

Importance of Multiple Cropping

The extent to which multiple cropping is practiced in Asia varies widely from one country to another, with the cropping index ranging from a low of 108.5% in Pakistan to a high of 184.3% in Taiwan (Table 1.2). However, with the rapidly increasing population and the dwindling area of new lands that can be cultivated in the humid tropics of Asia, multiple cropping is expected to gain more importance. Some of the reasons for this are that:

a) The multiple-cropping index is generally higher with smaller farm size (Table 1.3). With the expected decrease in farm size, the intensity of land use is expected to increase.

b) Multiple cropping is a simple and inexpensive strategy for absorbing the rapidly increasing number of farm labourers. Labour requirement per hectare usually increases as the number of crops grown per year is increased (Table 1.4). The addition of one more crop to the paddy rice, for example, could absorb an additional 100 to 200 man-days of labour per hectare.

c) With the more productive and fertile flat lands already cultivated, expansion to new areas will have to use the erosion-prone hilly lands. For these areas, multiple cropping is an excellent strategy for reducing soil erosion by rapidly providing adequate vegetative cover. In Nigeria, for example, soil loss and rainfall run-off in areas with 15% slope were reduced by 38 and 37%, respectively, by intercropping corn with cassava (Aina et al. 1977). Also, zero tillage and mulching, two management practices commonly used in

Table 1.2. Area of multiple cropping and the corresponding cropping index in some Asian countries

		Multiple cropping	
Country	Period	Area (100 ha)	Index[1] (%)
Burma	1965-66	983	111.1
Bangladesh	1968-69	3854	119.2
India	1966-67	22025	114.4
Indonesia	1964	2385	126.2
Japan	1967	1669	126.0
South Korea	1969	1397	153.4
Pakistan	1967-68	1385	108.5
Philippines	1960	2264	136.0
Taiwan	1969	866	184.3
South Vietnam	1960	282	112.5

[1] An indicator of the number of crops harvested per year from the same parcel of land; computed as annual harvest area divided by cultivated area and multiplied by 100.

Source: Darlympe (1973).

Table 1.3. Relationship between farm size and multiple-cropping index in Taiwan and in Java

	Multiple-cropping index (%)	
Farm size (ha)	Taiwan[1]	Indonesia[2]
<0.5	205.1	145.5
0.5-1.0	196.9	132.4
1.1-1.5	187.5	122.9
1.6-2.0	180.0	115.4
2.1-3.0	170.0	105.0
3.1-5.0	154.9	93.5
>5.0	131.6	58.8

[1] Source: 1970 Agriculture Census of Taiwan (Wang and Yu 1975).
[2] Source: 1963 Agriculture Census of Indonesia (Birowo 1975a).

Table 1.4. Labour requirement for some cropping patterns in selected countries of Asia

	Labour requirement (man-days/ha/yr)			
Cropping pattern	Taiwan[1]	Indonesia[2]	Philippines[3]	Bangladesh[4]
Rice	na	na	105	134
Rice - UC[5]	217	423	214	na
Rice - rice	192	490	210	237
Rice - rice - UC	295	na	255	na
Rice - rice - vegetable	423	na	na	na
Rice - UC - UC	na	687	na	na
Corn + rice	na	276	na	na
Corn + rice + peanuts	na	605	na	na

[1] Source: Mao (1975).
[2] Sources: Birowo (1975b); Ismail and Suprato (1978).
[3] Sources: Gines et al. (1978); Magbanua et al. (1978).
[4] Source: Hoque et al. (1978).
[5] UC = Upland crop.

multiple cropping, have been found to be effective in reducing soil erosion (Lal 1980).

d) With the rainfall pattern in the humid tropics of Asia characterized by excess water during the rainy months and too little water during the dry months, multiple cropping is a natural strategy for maximizing land use through the proper choice of crop species to fit to these cyclical changes in water regimes.

e) With the already large, and still increasing, number of rural population and the inadequate capital resources in the developing countries of the humid tropics, multiple cropping is an excellent alternative to capital-intensive industrialization for increasing the income among the least priviledged rural population.

Terminology in Multiple Cropping

With the growing interest in research into multiple cropping in recent years, many new terms have been devised by different workers for use in describing the different types of cropping patterns. To minimize confusion, terms that will be repeatedly used in the succeeding chapters are defined here. Most of these have been adopted, with minor modifications, from Harwood (1979).

Crop-Production Strategy

A *crop-production strategy* refers to a subset of the farm production strategy that involves only crops as its components. It is described by the spatial and temporal arrangement of crops to be raised in a parcel of land (*cropping pattern*) and the procedure for growing each component crop (*component technology*). A crop-production strategy can be either one of *monocropping*, a method of crop production in which only one crop is grown annually in the same parcel of land; or *multiple cropping*, a method of crop production in which several crops are grown annually in the same parcel of land.

Sequential Cropping

Sequential cropping refers to the growing of two or more crops in sequence on the same field within a 12-month period, with the succeeding crop planted only after the preceding crop has been harvested, such that a farmer manages only one crop at any one time in the same field. The different types of sequential cropping are: *double cropping*, a sequential cropping with two crops; *triple cropping*, a sequential cropping with three crops; *quadruple cropping*, a sequential cropping with four crops; and *ratoon cropping*, a sequential cropping with a ratooned crop (i.e., the cultivation of regrowth from the cut stalks of the previous crop).

A sequential cropping is denoted with a hyphen (-) between any two succeeding crops. For example, a double cropping of rice followed by mung beans is written as rice - mung beans; and a triple cropping of rice followed by rice followed by corn is written as rice - rice - corn.

Intercropping

Intercropping is the growing of two or more crops simultaneously on the same field such that the period of overlap is long enough to include the vegetative stage. There are two types of intercropping techniques: *mixed intercropping*, an intercropping with no distinct row arrangement; *and row intercropping*, an intercropping where at least one crop is planted in rows.

Intercropping is denoted with a plus sign (+) between any two crops grown simultaneously. For example, an intercrop of corn and mung beans is written as corn + mung beans. Thus, an intercrop of corn and mung beans followed by corn will be written as corn + mung beans - corn.

Note that when the overlap period is shortened by delaying the planting of the second crop after the first crop has already flowered, the cropping pattern is *relay cropping*.

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Relay Cropping

Relay cropping refers to the growing of two or more annual crops simultaneously in the same field such that one crop is planted after the other has flowered. Relay cropping is denoted with a slash (/) between crops. For example, the cropping pattern denoted by rice/mung beans - corn is a relay crop of mung beans after rice which is followed by corn.

Note that if planting of the second crop is done before the flowering stage of the first crop, the cropping pattern is *intercropping*.

The Multiple-Cropping Approach

There are three levels in which a crop-production strategy can be packaged and evaluated. These are the crop level, the cropping-pattern level, and the farm level. At the crop level, the package puts together the component technology required for the culture of each individual crop with the aim of maximizing productivity of that crop without consideration of the consequences to other crops in the cropping pattern. At the cropping-pattern level, the package specifies the management of all the crops in the cropping pattern as a whole with the aim of maximizing productivity of the whole pattern in a given piece of land. At the farm level, the package specifies the management of a group of cropping patterns that are to be implemented in the different parcels of land in the same farm.

Throughout this book, the packaging and testing of a production technology is always done at the cropping-pattern level. Three reasons for this choice are:

1) The biological interaction among crop components in a cropping pattern is expected to be large, such that the performance of a given crop is greatly dependent upon its particular position in the cropping pattern.
2) The biological interaction among different cropping patterns located in separate parcels of land in a given farm is expected to be negligible.
3) There is, at present, a lack of appropriate methodology for the evaluation of technology at the farm level.

Because of the shift from a single crop to a cropping pattern as the basic unit of a crop-production strategy, three major complications are expected.

Large Technology x Environment Interaction. With the longer growing season required by the cultivation of more crops in the same parcel of land, the effect on productivity of environmental changes from one location to another is expected to increase. This is to be expected because variation among locations in terms of water availability, a major determinant of yield, is most pronounced at the early and later parts of the growing season. Although these variable and risky periods can be avoided in monocropping by planting the crop only during the midseason, the long growing season required by multiple cropping requires that some crops be grown even during these variable periods. Thus the range of suitability of a particular production strategy for multiple cropping is expected to be smaller than that for a monocrop-production strategy. Therefore, more locations are required for testing multiple cropping than for monocrop-production strategies.

Many Alternative Measures of Productivity. Although the yield (weight or volume) is the most acceptable measure of productivity in monocropping in which only one major product is produced, this same measure is not as meaningful in multiple cropping in which the products are many and are usually heterogeneous with respect to nutritional and economic value. Thus, in multiple cropping, many alternative indices are possible and each experiment must identify the index (or indices) that best suit(s) its stated objective.

Difficult for Farms to Adopt. Farmers' adoption of intensive cropping patterns entails many difficulties, namely: the need to grow new and unfamiliar crops; the need for timely implementation of required practices; and the need for additional resources.

Focus on Asia

The primary focus of this book is the humid tropics of Asia, a region that is characterized by high population density, small farm size, and low farm income. Although much of the empirical data comes primarily from a few countries (i.e., Philippines, Indonesia, Thailand, and India), the production technology and the research methodology derived from these data are applicable to most areas in the region. However, they are less applicable to the humid tropics of Africa and South America where population density is lower and farm sizes are larger.

The Philippines experience on technology dissemination is an illustration of how a country can hasten the transfer of technology from research stations to farmers' fields. This experience, however, is not expected to be directly applicable to any other country, even in Asia; and would need some modification to fit the existing organization of public institutions as well as the infrastructure, customs, and tradition of the farm communities.

PART I

PRODUCTION TECHNOLOGY

CHAPTER 2: MULTIPLE CROPPING WITH LOWLAND RICE

Rice is the most important agricultural crop of South and Southeast Asia with a yearly harvest area of 83.4 million hectares, 31% of the arable land. Its popularity can be attributed to at least three factors. First, the crop is suited to the humid tropical environment of Asia. Except for taro, rice is the only major food crop that can be grown in standing water, making it uniquely suited to the vast areas of flat and low-lying tropical soils in Asia that flood annually during the rainy monsoon season (Chandler 1979). Secondly, rice is the most important food staple of the region with a per capita consumption exceeding 100 kg in most countries (Table 2.1). Thirdly, rice is the most marketable commodity in the region. The grain is easy to store and its market demand is high. Thus, the farm household can always keep the grain for future use if market price at harvest time is unfavourable. Not surprisingly, in the remote farms of the region, the family's well-being is generally gauged by the quantity of rice in the household.

Table 2.1. Annual production and per capita consumption of rice in some countries of Asia

Country	Production (million t)	Per capita consumption (kg)
Bangladesh	16.96	161
Burma	8.40	174
China	108.34	72
India	64.11	73
Indonesia	21.17	121
Japan	15.67	107
Kampuchea	1.40	137
Laos	0.87	202
Malaysia	1.95	113
Nepal	2.45	104
Philippines	5.48	89
South Korea	5.90	136
Thailand	13.95	203
Vietnam	10.99	293

Source: Chandler (1979).

Types of Rice Culture

Based on the level of water in which the crop is grown, rice culture can be classified into three types: upland rice, which is grown in unsubmerged and well-aerated soils; lowland rice (either rain-fed or irrigated), which is grown on fields (paddies) that are enclosed with earthen bunds (levees) such that enough water can be impounded to submerge the soils for most of the growing period; and deep-water rice, which is grown in the floodplains where the water level at some parts of the growing season exceeds one metre.

This chapter is devoted primarily to lowland rice, the most extensive and the most important among the three types of rice culture (Table 2.2). Upland rice is discussed in Chapter 3 together with the annual upland crops. Deep-water rice is not covered at all because the development of new production technologies for multiple cropping under this condition has not been substantial.

Table 2.2. Gross harvest area for the different types of rice culture for Asia and other parts of the world

	Gross rice area (million ha)				
Country	Rain-fed	Upland	Deep-water	Irrigated	Total
South and Southeast Asia	41.5	8.2	6.9	26.8	83.4
Bangladesh	4.4	2.2	1.9	1.0	9.5
Burma	4.3	neg[1]	neg	0.8	5.1
India	18.7	2.4	2.4	14.9	38.4
Indonesia	3.4	1.4	0.4	3.3	8.5
Laos	0.4	0.2	0.0	0.1	0.7
Malaysia	0.2	0.1	0.0	0.5	0.8
Nepal	0.9	0.1	neg	0.2	1.2
Pakistan	0.0	0.0	0.0	1.6	1.6
Philippines	1.6	0.5	0.0	1.4	3.5
Sri Lanka	0.2	0.1	0.0	0.3	0.6
Thailand	3.7	0.8	1.7	2.0	8.2
Vietnam	3.7	0.4	0.5	0.7	5.3
China	2.7	0.7	0.0	30.7	34.1
Other developing countries	1.6	4.8	0.0	3.9	10.3
USA, Japan, USSR	0.0	0.1	0.0	4.1	4.2
Others	na	na	na	na	5.2

[1] Negligible.
Source: Barker and Herdt (1979).

Features of the Lowland Rice Paddies

The distinguishing features of the lowland rice paddies emanate primarily from their submergence in water during most of the rice-growing period, and are the following:

Small Plots Enclosed with Levees. To submerge the soil efficiently, the farm is divided into small plots, or paddies, each of which is carefully leveled and enclosed with earthen walls, or levees.

The paddy size varies widely both within, and among, farms. A major determinant of paddy size is the labour required for leveling the land and making the levees. Note that the amount of earth movement required to effect leveling within a paddy increases substantially as the paddy size increases. On the other hand, the smaller the paddy the more levees are needed per farm. Thus, paddy size is usually selected to minimize the cumulative labour required for land leveling and for levee making. In the Philippines, the usual paddy size for farms in the plains is about 500 to 1000 m^2 whereas that in the sloping areas is usually smaller than 500 m^2.

Land Preparation under Submerged Soil Condition. Although, for most crops, the seed bed is prepared when soil moisture is less than field capacity, that for lowland rice is prepared when the soil is saturated with water or submerged. This results in what is generally termed as puddled soil. In contrast to the normal upland soil, which is prepared when the soil is dry, the puddled soil is characterized by smaller particle size, lower hydraulic conductivity, higher bulk density, and more neutral reaction (Table 2.3).

Table 2.3. Comparison of some soil properties in puddled and upland conditions

Soil property	Puddled soil	Upland soil	Source
Particle size	small	large	Ghildyal 1978
Hydraulic conductivity	low	high	Ghildyal 1978
EC (mmho/cm)	1.25	0.96	Ghildyal 1978
Bulk density (g/cm^3)	1.71	1.54	Ghildyal 1978
Redox potential (mV)	100 to -100	700 to 500	Patrick and Reddy 1978
pH (acidic soils)	high	low	Yamane 1978 Ponnamperuma 1978
pH (alkaline soils)	low	high	Yamane 1978 Ponnamperuma 1978

The main advantage of preparing wet land is that it does not need the precise timing of plowing and harrowing so necessary in the dry bed preparation. Cultivation can continue in spite of inclement weather. Other advantages of the wet land preparation are these: First, that land preparation can be spread over a longer time, thus allowing the farmer to use his limited man- and animal-power more efficiently; secondly, that weed control is more effective; thirdly, that reduced soil condition improves soil fertility and fertilizer management; fourthly, that lower penetration resistance reduces the draft requirement for tillage; and lastly, that reduced percolation losses improve water conservation (De Datta et al. 1978).

A major drawback in preparation of the wet seed bed, however, is that it requires a lot of time and water, both of which are very valuable in multiple cropping. Between 200 to 700 mm of water is used during land preparation for transplanted rice (Wickham and Sen 1978). Even with heavy rainfall in the humid tropics, two to three months elapse from the first rain until the time when rice can be transplanted. By plowing the paddy when it is still dry, Singh and De Datta (1978) were able to dry seed about 2.5 months earlier than the normal date of transplanting in Laguna, Philippines. An analysis of rainfall data in Iloilo and Pangasinan, Philippines, indicates that rice can be direct seeded 30 to 50 days before the time when 400 mm of rainfall, the estimated water requirement for soil puddling, has accumulated (De Datta et al. 1978).

Poor Drainage. To retain water in the paddy, much of the natural drainage is destroyed and, with soil puddling, water seepage is minimized. Through land leveling and enclosure with levees, much of the surface drainage becomes ineffective. Thus, a rice paddy cannot be easily dried and converted to a well-drained upland soil.

Extensive Use of Irrigation. Rice is the most important beneficiary of irrigation. Of the 34.1 million ha of rice in China, 90% is grown under irrigation and, in South and Southeast Asia, about 33% of the rice areas are irrigated (see Table 2.2). There are three major reasons for the dominance of rice in the use of irrigation facilities. First, as the most important staple of Asia, rice is generally given the highest priority by national programs to provide enough food for the rapidly increasing population. Secondly, rice areas are uniquely suited for gravity irrigation, the cheapest and most popular method of irrigation. Rice lands are leveled and enclosed with levees that efficiently impound excess water; and, since most rice areas are in the low-lying valleys, they are strategically located for gravity irrigation. Thirdly, the water requirement for rice culture is high and the potential improvement in yield due to irrigation is substantial (Table 2.4).

Small Farms. Most rice farms are located in the flat and fertile valleys that contain most of the centres of population. Consequently, the rice farms are generally small (Table 2.5) and land use is usually intensive.

Role of Multiple Cropping in the Lowland Rice Paddies

There are several reasons why multiple cropping is an attrac-

Table 2.4. Yield potential of irrigated and rain-fed rice in some countries of Asia

Country	Maximum yield[1] (t/ha)		
	Rain-fed	Irrigated	
		Wet season	Dry season
Bangladesh	3.7	4.9	6.6
India	4.0	5.4	6.8
Indonesia	3.6	4.8	5.9
Philippines	3.5	4.6	5.9
Sri Lanka	4.0	5.3	5.7
Thailand	2.5	3.7	4.4
Vietnam	3.1	4.1	5.8

[1] Average maximum yield obtained from trials in farmers' fields.
Source: Chandler (1979).

Table 2.5. Distribution of rice farms in Asia by size

Country	Total area (1000 ha)	Frequency of farm size (%)					
		<0.5 ha	0.5-1.0 ha	1.1-2.0 ha	2.1-3.0 ha	3.1-4.0 ha	>4.0 ha
South Asia	64,115	22	19	22	12	7	18
Bangladesh	6139	28	24	26	11	4	7
India	49,874	21	19	22	12	7	18
Nepal	2076	30	14	15	8	8	24
Pakistan	4860	17	15	17	12	8	31
Sri Lanka	1166	39	26	19	6	6	4
Southeast Asia	19,899	33	20	21	10	5	11
Indonesia	12,237	44	26	18	6	2	4
Malaysia (West)	450	15	22	31	16	6	10
Philippines	2166	4	7	30	21	12	26
Thailand	3174	10	7	22	17	11	32
Vietnam	1872	37	19	22	10	4	8
East Asia	8405	38	31	25	6[1]		
Japan	5176	38	31	25	6[1]		
Korea	2452	36	32	26	6[1]		
Taiwan	777	37	29	24	10[1]		

[1] Larger than 2 ha.
Source: Harwood and Price (1976).

tive technology for use in the rice paddies. First, with high population density, small farm size, and farming as the main source of employment, the amount of labour that can be absorbed per unit area of land must be maximized. The most obvious way is to increase cropping intensity by growing additional crops. For example, by growing another crop after rice, labour absorption per unit area of land is more than doubled (see Table 1.4)

Secondly, the rapidly developing infrastructure has greatly increased the number of alternative production strategies open to farmers. With improving markets, for example, vegetables and fruits such as cabbages, tomatoes, and watermelons, which may have been uneconomical to grow commercially before, have become feasible alternatives because their profit potential is much higher than that of the grain crops.

Thirdly, the physical environment favours the growing of non-rice crops at certain times of the year. Due to its high water requirement, rice is usually grown during the peak rainy months; however, during the drier periods, other crops that are more tolerant to low water supply are more suitable. Thus, upland crops may be planted in rain-fed rice paddies during the dry months of the year.

The Traditional Cropping Pattern

The most commonly used cropping pattern in the traditional lowland rice paddies is a single rice crop that is characterized by a prolonged period of land preparation under submerged conditions, the transplanting of rice seedlings at the peak rainy period, and the use of photoperiod varieties that mature at the end of the rainy period.

Land Preparation

Land preparation for the traditional single rice crop consists of a series of plowing and harrowing operations under submerged conditions that can last for as long as three months. This prolonged period of land preparation is uniquely suited to the traditional rice farms in which labour is the most limiting resource. For these farms, the best time to plant the single rice crop is during the most rainy months of the year which usually occur two to three months after the onset of the first monsoon rain. Thus, land preparation can be staggered over this period without adversely affecting the time of planting. This procedure of land preparation allows the farmer an opportunity to maximize the use of his limited farm labour and animal power. For example, it takes approximately 20 man-days to prepare one hectare of paddy land. A farmer with only one draft animal can cultivate up to three hectares if there are 60 days available for land preparation but only one hectare if this period is reduced to 20 days.

Transplanting

Transplanting coincides with the peak rainy periods and uses seedlings that are about 25 to 40 days old. This procedure confers three significant advantages: First, the probability of water stress immediately after transplanting, when the seedlings are very vulnerable to drought, is greatly reduced; secondly, with the use of the fairly tall pregerminated seedlings, transplanting can be done even when there is excess water in the paddy; and thirdly, with the wide range of seedling age used in transplanting, staggered planting is possible.

Use of Photoperiod-Sensitive Varieties

The traditional varieties of rice used in the single rice cropping pattern are usually photoperiod sensitive so that flowering and maturity occur uniformly during the short days of November to January. This period of maturity occurs almost independently of the planting time, i.e., when a photoperiod-sensitive variety is used, the crop will mature in the same month, say December, regardless of whether planting was in August or September. Its maturing coincides with the tail end of the monsoon and the start of the dry season, at which time the frequency of sunny days is rapidly increasing while the soil has still enough moisture to support the maturing crop. This condition is ideal for harvesting since the wet grain can be conveniently and cheaply dried in the sun.

New Technologies for Intensive Cropping

With the rapidly increasing population and the dwindling supply of new lands that can be developed into rice farms, much research has been undertaken on the intensification of land use in existing rice paddies. Significant results of these research activities can be grouped into four categories: the development of varieties of annual upland crops that are uniquely suited to the environment of the rice paddy; the development of fast-maturing varieties of rice; the modification of the cultural practices of annual upland rice crops to suit the rice paddy; and the modification of the rice culture to accommodate additional crops.

Varietal Improvement in Annual Upland Crops

Traditionally, crop-improvement programs have been conducted under the most favourable environment, i.e., the best cultural and management practices are provided during the selection and yield testing phases, on the assumption that the best varieties under ideal conditions are also the best under less favourable environments.

With multiple cropping, the diversity between the ideal and actual environments under which a crop is grown is expected to increase, such that the best varieties selected under ideal conditions may not be best under multiple-cropping conditions.

In recognition of this, a breeding program was initiated at the University of the Philippines at Los Baños (UPLB) to develop varieties that are specifically suited for sequential cropping with lowland rice.

Promising varieties and breeding lines of corn, sorghum, mung beans, peanuts, sweet potatoes, tomatoes, and eggplants were screened for planting before and after the main rice crop (VSIC 1979).

Crops before Rice. If the main rice crop is to be transplanted during the peak rainy period of the year, in some locations there is enough time to grow a fast-maturing annual crop between the first monsoon rain and the time of transplanting. This growing period is characterized first by a high probability of water stress at the seedling stage because rainfall is usually uncertain at the early part of the monsoon season, secondly by excess water at maturity because harvesting usually coincides with the approaching peak rainy months, and thirdly by a short growing period (60 to 90 days) because the crop must mature early enough for the planting of rice during the peak rainy months.

Under these conditions, the crops to be grown must mature early, must have good seedling vigour, and must tolerate heavy rainfall at maturity. These three requirements are not easily satisfied by annual upland crops. Dried mung-bean pods, for example, quickly deteriorate under heavy rainfall whereas sorghum takes too long to mature.

The crops uniquely suited for these conditions are the grain crops grown as vegetables, such as green corn, cowpeas, and green soybeans (Table 2.6). Because the cobs or pods are harvested at the green stage, which is usually 20 days after pollination, the crop can be

Table 2.6. Varieties of annual upland crops found suited for planting before lowland rice

Crop/Variety	Yield (t/ha)	Maturity (days to harvest)	Plant height (cm)
Mung beans (bean dry grain)			
1F-5	1.13	65	106
2V-8	1.05	65	89
3Q-13	0.98	64	88
Bhacti	0.94	64	88
Green corn (husked green ears)			
Sweet DMR comp. 32A	6.66	71	203
Super sweet comp.	6.41	69	194
Glutinous DMR comp. 41B	5.85	70	188
Glutinous DMR comp. 41A	4.95	70	189
EG Glutinous 7	4.93	73	195
Cowpeas (green pods)			
Accession # 285	9.64	58	174
Accession # 299	8.95	61	67
BPI Improved Green # 2	8.95	59	137
Accession # 297	8.45	68	143
All season	8.39	58	155
Accession # 30	6.72	62	na

Source: VSIC (1979).

harvested early (less than 80 days). Also, the green pods or cobs do not deteriorate under heavy rainfall, and harvesting can be completed even under very wet conditions.

Crops after Rice. After the main rice crop is harvested, it is soon possible to plant another crop. Its growth conditions are characterized by adequate moisture at planting, moisture stress at the later stages, and a much longer growing season. Because the rice crop is usually harvested at the tail end of the rainy season when the soil is still wet, there is usually enough water to carry the succeeding crop for at least two weeks even without additional rainfall. However, at one month after planting, hardly any rain will fall and water stress can be expected.

Some of the crops that are suited to this condition are sorghum, soybeans, and mung beans (Table 2.7). These grain crops have good seedling vigour, are very tolerant to water stress after flowering, and can produce good yields in spite of dry conditions during the latter stages of their growth. The yield levels of the selected varieties are fairly high indicating that the after-rice environment is favourable for the annual upland crops and that high-yielding varieties from these species are not difficult to find.

Development of Fast-Maturing Varieties of Rice

Under the traditional method of rice culture in which only one crop is grown per year, fast-maturing varieties (i.e., varieties with a short growth duration) provide very little advantage, if any, over the slow-maturing photoperiod-sensitive varieties. However, as the intensity of land use increases and another crop is added into the cropping pattern, early maturity in rice is desirable for two reasons. First, with a shorter growing period, it is easier to avoid unpredictable rainfall and water availability both at the start and at the end of the rainy period. Secondly, with the shorter growing period, there is more freedom for selecting a more favourable planting time for the annual upland crops that are grown in sequence with rice. Both of these advantages result in a much lower chance of crop failure and, thus, a more stable cropping pattern.

Substantial progress has been achieved by the International Rice Research Institute (IRRI) in its breeding program to develop fast-maturing varieties of rice. Maturity and grain yield of six of the quickest-maturing selections and three named high-yielding varieties are given in Table 2.8. Compared to IR 36 (the quickest-maturing high-yielding variety), maturity in the new selections is shorter by up to 20 days per crop, which could shorten the yearly rice growing period by more than one month. In terms of the grain yield per hectare per day, the fast-maturing selections are as good as IR 36 and generally better than IR 54 and IR 42 the medium- and slow-maturing high-yielding varieties.

Modification of Cultural Practices in Rice

The wet land preparation for lowland rice has a major drawback in that a lot of time and valuable water is wasted to thoroughly wet,

Table 2.7. Annual upland crops found suited for planting after lowland rice

Selection Variety	No. of trials	Grain yield (t/ha)	Maturity[1] (days to harvest)	Plant height[1] (cm)
Mung beans				
CES 55	11	1.43	66	57
MG 50-10A	6	1.33	66	59
M 350	11	1.32	65	53
CES 14	6	1.24	68	71
CES 10-21	8	1.20	67	46
CES 1F-10	6	1.18	67	41
CES 87	9	1.16	66	58
CES X-10	6	1.14	69	42
Field corn				
Thai comp. 1 Early	3	5.37	90	134
Med. Early DMR comp. 1	3	4.83	90	214
Phil. DMR comp. 3	1	4.33	89	203
Med. Early DMR comp. 2	7	3.66	89	188
Early DMR comp. 1	7	3.62	89	184
Phil. DMR comp. 1	10	3.53	91	187
Soybeans				
Williams	7	1.15	87	38
Clark 63	13	0.94	80	39
Lincoln	12	0.90	81	53
UPLB -SY-2	9	0.90	77	36
Multivar 80	11	0.84	83	34
Sorghum				
CS 107	9	5.42	89	128
CS 105	9	4.15	90	120
UPLB SG 5	11	3.63	89	122
CS 108	12	3.25	88	116
D 67-4	11	3.06	88	130
D 67-1	8	2.66	88	128
Cowpeas				
EG # 3	7	1.55	73	103
EG # 2	11	1.45	72	79
All season	11	1.36	72	82
121	1	1.06	59	45
122	1	1.01	57	44
Peanuts				
CES 103	3	2.09	97	44
M-10	7	2.05	101	36
Gadjah	6	1.74	100	35

[1] Not measured in all trials.
Source: VSIC (1979).

Table 2.8. Grain yield for 1979 dry season of six early-maturing selections and three named varieties of rice developed at IRRI

Selection/Variety	Growth duration (days)	Grain yield	
		t/ha	kg/ha/day
IR 9752-303-3-1-3	102	6.5	64
IR 9758-150-3	102	6.3	62
IR 10154-23-3-3	90	5.3	59
IR 10154-117-2-3	90	5.2	58
IR 10179-2-3-1	96	6.1	64
IR 13168-143-1	102	6.3	62
IR 36	110	6.9	63
IR 54	120	7.1	59
IR 42	135	7.0	52

Source: Unpublished data of the Department of Plant Breeding, IRRI; cited with permission from G.S. Khush.

submerge, and finally puddle the rice paddy soil. To remedy this disadvantage, some modifications to this traditional rice culture have been tried. The most promising alternative is dry seeding, for which the land is prepared during the summer months so that its preparation resembles a typical upland culture in which the seed bed is well-pulverized and aerated. Soon after the first monsoon rains, rice seeds are sown directly into the seed bed. In dry-seeded rice, seeds start germinating soon after the monsoon rains so that the growing season is effectively lengthened. The term dry seeding is used to differentiate it from two other methods of seedling establishment: transplanting, in which seeds are pre-germinated in special seed beds before they are transplanted to a submerged paddy; and wet seeding, in which rice seeds are broadcast into a submerged and puddled seed-bed.

Thus, by dry seeding fast-maturing varieties, two crops of rice can be grown on the same piece of land where only one was grown before (Figure 2.1). Because grain yield from dry seeding can be as high as that from transplanting (Table 2.9), a substantial increase in yield per year can be expected from the additional crop.

Cultural Practices in Other Crops

A major consequence of puddling for lowland rice is the destruction of soil structure, which makes it extremely difficult to convert into a well-aerated field for growing upland crops. This problem is most pronounced in the rice paddies where the heavy-textured puddled soil can only be converted to a well-aerated field through a series of intermittent dryings and wettings interfaced with cultivation. This process is possible only with a favourable schedule of sunshine and of moisture supply from rain or irrigation.

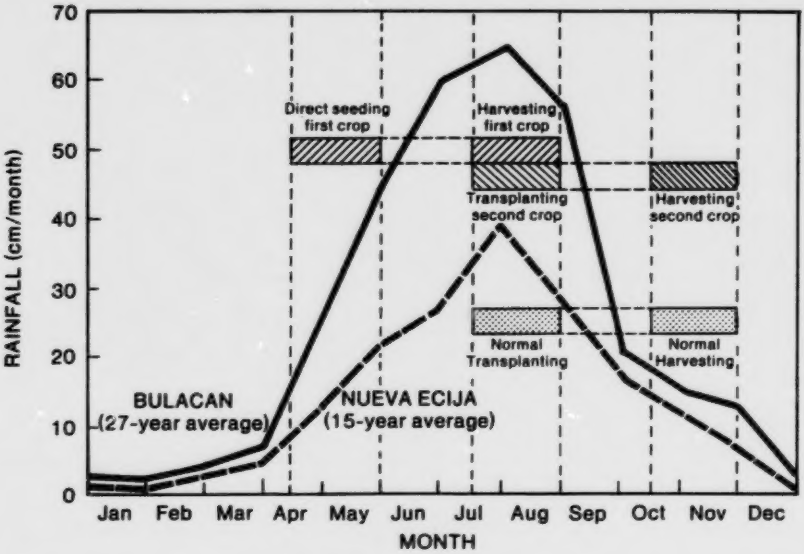

Figure 2.1. Monthly rainfall in Bulacan and Nueva Ecija, Philippines, with planting and harvesting periods shown for rice grown under the normal transplanted crop and the two-crop system (after Athwal 1974).

Table 2.9. Relative yield of transplanted and dry-seeded rice obtained from on-farm trials in Iloilo and Pangasinan, Philippines, 1977

Location	Seedling establishment	No. of fields	Grain yield (t/ha)	Source
Iloilo	dry-seeding	12	5.0	Interdisciplinary Research Team 1978
	transplanting	9	5.0	Interdisciplinary Research Team 1978
Pangasinan	dry-seeding	50	4.5	Gines et al. 1978
	transplanting	26	4.0	Gines et al. 1978

Even when the moisture availability allows for the conversion of a puddled paddy to a well-prepared upland seed bed, the procedure is not usually followed for several reasons. First, the process is difficult and expensive because repeated plowing and harrowing is needed before the heavy puddled soil is converted to a well-pulverized seed bed. Secondly, the chance of establishing a successful crop after rice using this procedure is very low, i.e., when the upland seed bed is finally ready, there might not be enough rain to support the crop to maturity; and, even if the crop is successful, its return may not be enough to pay for the difficult and expensive conversion procedure involved. Thus, if farmers are to be encouraged to plant annual upland crops after rice, a technique that can overcome these difficulties must be provided.

A promising procedure, termed zero tillage, is to forego cultivation altogether; in which case, the difficult and expensive process of plowing and harrowing is avoided. In addition, the lag time from rice harvest to seeding of the next crop is shortened and moisture saving is, thus, enhanced. The procedure consists of the following three steps.

First, the paddy is drained two to three days before the rice is to be harvested. Soon after, or even at the time of, harvest the rice straw is cut very close to the ground.

Second, shallow drainage canals are dug along the levees to improve surface drainage and prevent waterlogging. The next crop is seeded immediately after harvesting the rice in order not to give much headstart to the emerging weeds.

Third, the seed of the next crop is drilled right beside the newly cut rice straws, for two reasons: First, some degree of aeration is provided by the looser soil near the rice hill; and secondly, the area near the rice hill is usually elevated by a few millimetres relative to the other parts of the paddy, which minimizes submergence of the newly planted seed.

The comparative yield data for some upland crops under zero and normal tillage are given in Table 2.10.

Reaction to zero tillage differed greatly among species with

Table 2.10. Relative yields in variety trials of annual upland crops grown under zero and high tillage

Crop	No. of trials	No. of varieties	Yield (t/ha) High tillage	Yield (t/ha) Zero tillage	Yield reduction (%)	Trials with insignificant correlation[1]
Sorghum	6	90	3.07	3.46	-13	3
Soybeans	4	51	0.65	1.03	-58	2
Mung beans	3	37	1.19	0.96	19	3
Corn	2	24	2.46	2.01	18	1
Sweet potatoes	2	19	19.80	10.89	45	0

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[1] Correlation in grain yield between high tillage and zero tillage.

Sources: Carangal et al. (1976, 1977); VSIC (1979).

Table 2.11. Economic analysis for some annual upland crops planted after lowland rice at different tillage levels; from on-farm trials in Iloilo, 1976 to 1977

Crop	Tillage level	No. of fields	Yield (kg/ha)	Labour cost ($/ha)	Net return ($/ha)
Cowpeas	high	8	562	60	14
	zero	10	662	10	74
Mung beans	high	2	255	48	9
	zero	13	260	19	83
Soybeans	high	5	565	88	8
	zero	2	342	16	9

Source: Interdisciplinary Research Team (1978).

sorghum and soybeans generally showing better yields under zero tillage whereas the opposite is true for the other three species. Also, the correlations between varieties grown under the two environments were low and insignificant in 9 out of 17 trials, indicating that different varieties exhibited different degrees of tolerance to zero tillage and that the best varieties under high tillage need not be the best under zero tillage, and vice versa.

The labour cost and net returns of some upland crops planted immediately after rice under zero and high tillage are listed in Table 2.11. Note that, even for soybeans where there is a yield reduction due to zero tillage, the savings in labour costs are so substantial that average profit is higher and the probability of incurring financial losses is much lower.

Some Important Cropping Patterns

Sequential cropping is the most suitable cropping pattern in the rice paddies. The puddled and submerged soil condition in which lowland rice is grown limits the feasibility of other alternatives. Perennial crops, for example, would suffer severely under submerged conditions. The same can be said for most annual upland crops such that intercropping with lowland rice is generally not feasible.

Sequential cropping in lowland rice can be grouped into two patterns of importance in the rice paddies of Asia: First, the all-rice sequential cropping patterns, rice - rice (R - R), rice - rice - rice (R - R - R), rice garden; and secondly, the mixed rice and upland crops sequential cropping patterns: rice - upland crop (R - UC), upland crop - rice (UC - R), rice - rice - upland crop (R - R - UC), upland crop - rice - upland crop (UC - R - UC), and sequences of more than three crops.

The All-Rice Sequential Cropping Patterns

The all-rice sequential cropping patterns have several attractive features. First, the puddled soil condition is maintained all year long so that the problems associated with alternate puddling and dry-land cultivation are avoided. Secondly, rice is a very hardy crop and is exceptionally tolerant to waterlogging and strong winds -- the two common environmental hazards in the humid tropics of Asia. Thirdly, as mentioned earlier, rice is a familiar crop both in the farm and in the market: its culture is familiar to most farmers and the grain is easy to store and can be marketed locally anytime of the year.

Rice - Rice (R - R). The many advantages of the traditional single rice crop are achieved only at the sacrifice of time. In many parts of Asia where population is dense, where farm holdings are small, and where irrigation water is increasingly available, the traditional single rice crop is giving way to the more intensive patterns such as the rice - rice pattern.

The appeal of the rice - rice pattern is simple. Because the rainy months in many rice areas of the humid tropics of Asia span a period of eight or more months per year, and because rice matures in less than four months, it is possible to grow two crops of rice per year on the same piece of land even without irrigation. Thus, the use of land, which is the most limiting resource, is significantly increased, and more farm labour can be absorbed per unit area.

There are several significant consequences of converting to a rice - rice pattern. First, the long time period available for land preparation and for transplanting in the traditional rice culture is drastically reduced. The soil must now be prepared dry and planting must be done even before the first rain in order to give time for the second crop. Also, land preparation for the second crop must be done as quickly as possible so that planting can be completed early to avoid water stress from the oncoming dry season. Thus, the sequence of activities for the rice - rice pattern is characterized by precise timing and pronounced peaks in the labour requirement, which usually occur between the harvest of the first crop and the planting of the second crop. A much higher level of management relative to the single rice crop pattern is required of the farmer. Also, the time of planting and harvesting is determined more by the need to avoid time wastage rather than to suit the climatic condition. Consequently, the probability of water stress, specially at the seedling stage of the first crop and at the grain-filling stage of the second crop, is increased. Finally, the harvesting period for the first crop usually coincides with the peak rainy period such that sun drying becomes inadequate and artificial driers, which are much more expensive, may be required.

Based on the cost and returns of several cropping patterns tested in farms in the Philippines, Bangladesh, and Indonesia, the rice - rice pattern is one of the most productive and most profitable (Table 2.12). It is twice as productive as the single rice crop and is not much behind the more intensive rice - rice - upland crop pattern. It is not surprising, therefore, that the rice - rice pattern is probably the most commonly used in lowland rice paddies where rainfall is high or where irrigation water is available.

Table 2.12. Production, cost, and returns of some cropping patterns tested in several countries in Southeast Asia

Cropping pattern[1]	Country	No. of fields	Total production (t/ha)	Total value ($/ha)	Production cost Material ($/ha)	Production cost Labour ($/ha)	Net return ($/ha)	Source
R	Philippines	13	4.25	472	76	64	332	Magbanua et al. 1978
	Bangladesh	3	3.13	418	177	na[2]	241	Hoque et al. 1978
UC - R	Thailand	15	2.55	352	70	na	292	Chandrapanya 1980
R - UC	Thailand	3	7.60	1038	233	394	411	Boriboon 1980
	Philippines	64	6.34	930	209	136	585	Magbanua et al. 1978; Gines et al. 1978
R - R	Philippines	47	9.22	962	218	155	588	Magbanua et al. 1978; Gines et al. 1978
	Bangladesh	8	9.13	1218	509	na	709	Hoque et al. 1978
	Indonesia	6	8.76	1267	132	527	609	Saefuddin et al. 1977
R - R - UC	Philippines	13	9.81	1365	417	257	691	Gines et al. 1978
	Indonesia	5	11.02	1873	313	792	768	Saefuddin et al. 1977

[1] R = rice; UC = upland crop limited only to the grain crops.
[2] Only material cost is considered in computing net returns.

Rice - Rice - Rice (R - R - R). With three crops of rice, the paddy is cropped for at least ten months/year, which is possible only in irrigated areas where irrigation is adequate even during the dry months when hardly any rain is expected.

As in the rice - rice pattern, this pattern is also characterized by farm activities that are precisely timed and by a labour requirement that has pronounced peaks. Because the rice - rice - rice pattern can be used only on farms with very good water control, crop failure due to water stress is almost nonexistent. Furthermore, of the three rice crops, the most productive one is that which coincides with the dry months when solar radiation is high and the occurrence of other calamities such as typhoons or pest infestation is very low. Because of the ideal conditions under which this pattern is usually used, its stability and profitability are very favourable. However, its high water requirement greatly limits its applicability such that its area of coverage is much smaller than that for the rice - rice pattern.

Rice Garden. Rice garden refers to a cropping pattern in which rice is planted in small garden-like plots within the farm and harvested continuously at regular intervals throughout the year. This is achieved by subdividing the farm into small units, and by planting each at regular intervals. For example, for a 90-day rice variety such as IR 36, the farm can be subdivided into 45 small units, each of which is planted at regular two-day intervals. If the growing period of the rice variety is not affected by the time of the year in which it is planted, harvesting can also be done at two-day intervals and as many as four crops of rice can be harvested per plot per year provided that land preparation per crop does not exceed two days.

An example of a successful rice garden is the farm of L.P. Jose in Pampanga (Ranit and Drilon 1977). His 1.5-ha farm is divided into 107 plots ranging in size from 94 to 120 m^2. He grows five rice varieties with various lengths of maturity (65 to 90 days). By staggering the daily planting over 107 plots, harvesting is also staggered uniformly throughout the year. Six workers, including Mr Jose himself, provide a total of 70 hours of labour per day. Grain yield over a 12-month period was 28.8 t/ha resulting in a net value added of $2243 per year (Table 2.13).

The rice garden concept has been evaluated at IRRI since 1975 using plots ranging in size from 250 to 1000 m^2. The results show that it is possible to have a one-day turnaround time between crops so that at least four crops can be harvested per year from the same plot. Because there are no labour peaks, it is possible for one labourer working 40 hours/week to perform all the required activities for one hectare of land. Given for comparison in Table 2.13 are the results of the 1976 trial at IRRI, in a one hectare area, which showed an average yield of 5.9 t/crop and a total accumulated yield of 23.7 t over a 12-month period resulting in a net value added of $1488. A disadvantage of the system is that the labour requirement per unit area is higher for small plots; the cost of land preparation, for example, is 25% more in 250-m^2 plots compared to two-hectare plots (Morooka et al. 1979).

The rice garden is a very intensive type of culture that requires adequate water all year long and a large capital outlay for input of both material and labour. Consequently, this type of culture is not common and will probably remain so at least in the near future.

Table 2.13. Costs and returns per hectare per year of a rice garden cropping pattern grown on two farms in the Philippines

Item	IRRI farm	L.P. Jose farm
Production (kg)	23,648	28,800
Value ($)	3153	3840
Labour input (man-days)	614	1460
Cost of labour input ($)	722	2176
Materials inputs ($)	1151	1419
Capital cost ($)	514	178
Net return ($)	766	67
Value added ($):	1488	2243
Labour share (%)	48	97
Residual (%)	52	3

The Mixed Rice and Upland Crops Sequential Cropping Patterns

The growing of upland crops in rice paddies is justified primarily because of the limited water supply at certain times of the year. Since the water requirement of most upland crops is much lower than that of rice, it is logical to grow upland crops during those times of the year when there is insufficient water for rice.

There are many species that can be grown in sequence with rice, such as corn, sorghum, soybeans, peanuts, mung beans, tomatoes, eggplants, sweet potatoes, and other vegetables. Some of the varying characteristics that make them suitable for growing in sequence with lowland rice are the drought tolerance exhibited by sorghum and mung beans, fast maturity exhibited by mung beans, sweet corn, and cowpeas, and tolerance to excess rainfall at harvest exhibited by corn and some vegetable crops.

Since rice must be grown during times of high rainfall, the upland crops to be grown in sequence can be classified into those planted before, and those planted after, the rice crop. The main features of these two growing seasons and the species and varieties of upland crops that are adapted to these environments have been described under Crops before Rice and Crops after Rice, respectively.

Rice - Upland Crop (R - UC). The most commonly used cropping pattern in rain-fed rice paddies is that of rice - upland crop (R - UC). Mung beans are a popular choice in this pattern for several reasons. First, the seedlings are very hardy and germinate vigorously even in the uncultivated paddy. Secondly, mung beans usually mature in less than 75 days and have a high level of tolerance to drought, which often occurs after the rice harvest. Thirdly, the crop requires a minimum input of cash and its grain is easy to store and to sell.

Mung beans, however, are a low-yielding crop especially under zero tillage. The estimated average yield in Iloilo, the province with the largest area producing mung beans in the Philippines, is only about 300 kg/ha, although with improved management, the yield can be raised up to 800 kg/ha.[1] Experiments by Pookpakdi (1980) in Thailand showed that the yield of mung beans grown before lowland rice could be improved from 290 to 560 kg/ha by improving tillage practices and insect control. When grown after rice, the same improved practices increased mung bean yield from 400 to 710 kg/ha.

A promising alternative to mung beans is sorghum, a crop that has good seedling vigour and is known for its drought tolerance. Experiments at UPLB and at IRRI, both in the Philippines, have shown that sorghum can yield up to 4.0 t/ha of grain when planted immediately after rice.

Also gaining popularity in the densely populated areas of the Philippines are watermelons. Soon after the rice harvest, holes of 0.08 to 0.16 m^3 are dug in the moist paddies at intervals of about 1.5 m. Well-pulverized soils mixed with compost are then used to fill the holes upon which melon seeds or seedlings are planted. When no rain falls, each plant is watered manually using shallow wells that are dug nearby. Although the melon crop requires a high input of cash and labour (up to 270 man-days/ha), its yield is high (up to 10,000 fruits per/ha) and the net income per unit area of land is about twice that of the rice crop (MCEPP 1979).

The cost and returns of a rice - upland crop pattern vary widely with the species of the upland crop used. In general, upland grain crops like mung beans or sorghum require low labour and material input but the net returns are also low. Trials in Thailand and in the Philippines, for example, show the net returns per hectare per year for the rice - upland grain crop pattern to be $411 and $585, respectively (see Table 2.12). In comparison, a rice - tomato pattern is expected to give a net return of $873/ha (MCEPP 1979).

Upland Crop - Rice (UC - R). There are many constraints to growing upland crops before rice and only a few species can fit into this sequence. Those most commonly grown before lowland rice are green corn and cowpeas, both of which are popular in densely populated areas with good market outlets.

The upland crop - rice (UC - R) pattern is most suited to areas where the rainy season starts slowly so that the period between the first rain and the peak rainy months is long. With a longer growing season, seeding can be slightly delayed to ensure available moisture for the young seedlings.

This pattern is considered promising in Northeastern Thailand where annual rainfall is low (Table 2.14) and a single rice crop is normally planted at the mid-season when enough rain has fallen to puddle the soil. However, results of extensive trials indicated that the yield potential of the pre-rice upland crop is low, that net income from the upland crop component is generally negative, and that a single rice crop is as good if not better than the upland crop - rice pattern (Chandrapanya 1980). It seems that the low and unpredictable rainfall pattern in Northeastern Thailand is not sufficient to support a sequential cropping of two annual crops in the rice paddy.

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[1] A.C. Mercado Jr. (personal communication).

Table 2.14. Existing and potential cropping patterns for the different rainfall regimes in Southeast Asia

Location	Rainfall			Cropping pattern		Source
	Total (mm)	Wet months[1] (No.)	Dry months[2] (No.)	Existing	Potential	
Kohn Kaen, Thailand	1124	1 - 2	6 - 7	R	UC - R	KKU-FORD 1976
				UC	R - R	
Iloilo, Philippines	2057	5 - 6	5 - 6	R	R - R	Magbanua et al. 1978
				R - UC	R - R - UC	
West Java, Indonesia	2310	5 - 7	3 - 5	R	R - R	Syarifuddin 1975
				R - R - UC	R - R - UC	
					R - R - R	

[1] More than 200 mm rainfall per month.

[2] Less than 100 mm rainfall per month.

Rice - Rice - Upland Crop (R - R - UC) and Upland Crop - Rice - Upland Crop (UC - R - UC). These patterns are generally fitted for areas with evenly distributed rainfall or those with supplemental irrigation. The key to the success of these patterns are fast-maturing varieties and early planting of the first crop. For the rice - rice - upland crop (R - R - UC) pattern, the first rice crop must be direct seeded and planted before, or immediately after, the first rain of the season. Also, the second rice crop should be transplanted soon after the harvest of the first crop. Most of the problems prevailing in the rice - rice pattern discussed earlier also hold for the rice - rice - upland crop pattern. First, the labour requirement has very pronounced peaks from the harvest of the first crop to the transplanting of the second crop. Secondly, the harvest of the first rice crop coincides with the heaviest rainfall of the year and, hence, artificial drying is usually required. From the figures for the costs and returns for the rice - rice - upland crop patterns used in Indonesia and in the Philippines (see Table 2.12), the profitability of this pattern appears to be 18 to 26% more than that of the rice - rice pattern for the same areas.

The upland crop - rice - upland crop (UC - R - UC) pattern is a less-intensive pattern in which the most difficult crop in the pattern is the first upland crop. The crop chosen must be fast-maturing and its harvested grains must not need any drying. Green corn, cowpeas, or green soybeans are the most suitable crops, but, because of the limited choice in the first upland crops, this pattern is not as popular as the rice - rice - upland crop pattern.

Patterns with More than Three Crops. With the use of ratooning, of relay cropping, and of specialized cultural practices that avoid puddling in lowland rice, up to five crops can be harvested in the same paddy over a 12-month period (Bradfield 1970). Using paddies with adequate irrigation and good water control, Bradfield experimented at IRRI with various cropping patterns that could maximize productivity per unit area. The most successful pattern is a sequence of five crops consisting of rice, sweet potatoes, soybeans, sweet corn, and green soybeans. The tillage pattern varies for each crop and their days to harvest are 102, 100, 85, 66, and 60, respectively. This pattern gave a gross income per hectare of $3150, which is about three times that normally obtained in a rice - rice pattern. Two other cropping patterns, each with more than three crops per year, are the continuous vegetables cropping in Hong Kong, with as many as nine harvests per year (Luh 1969), and the mung bean - sweet corn - rice - mung bean pattern experimented at IRRI (1974). Because of the very expensive water and input requirements of these patterns, their use is limited to areas where population density is very high and land is very expensive.

Determinants of Cropping Patterns in Rice Paddies

Factors that influence crop productivity and profitability can be arbitrarily divided into those that the farmer can control and those that he can not (Norman and Palmer-Jones 1977). The controllable factors consist primarily of the management practices used on the farm such as pest control, fertilizer application, and cultivation. On the other hand, the uncontrollable factors are the physical and socio-economic environments of the farm such as climate, soil texture, topography, and product market, which are beyond the farmer's capability to modify. Although the controllable factors are usually modified to suit the crops being cultivated, the strategy for coping with the uncontrollable factors is to modify the cropping pattern. Thus, the uncontrollable factors are often referred to as determinants of cropping patterns. The three major environmental determinants are water availability, soil texture and topography, and market accessibility.

Water Availability

The primary distinguishing feature of a lowland rice culture is the submergence of the paddy for most of the life cycle of the rice plant. Consequently the water requirement in lowland rice is estimated to exceed 200 mm/month (IRRI 1977), which can be supplied either by rainfall or by irrigation. When irrigation water is available all year, the tendency is to grow rice continuously since continuous rice culture is much easier to manage than intermittent lowland and upland culture.

In many rice paddies, however, the high water requirement of rice cannot be satisfied throughout the year. Even with irrigation, available water during the dry months is usually not enough to flood the rice paddy continuously. Under such conditions, the alternative pattern is to grow rice in sequence with upland crops whose water requirements are much less (see Table 2.14). The intensity of cropping increases with the availability of water. Up to three crops per year can be grown even without irrigation in areas with evenly distributed rainfall that exceeds 2000 mm/year, such as in West Java, Indonesia, and in Iloilo, Philippines. As total yearly rainfall decreases and becomes unpredictable, such as in Khon Kaen, Thailand, where annual rainfall is less than 1300 mm, cropping intensity becomes limited to one rice crop only and the paddy is left fallow for the rest of the year.

A fairly wide choice of upland grain crops can be grown in sequence with rice. With low rainfall, mung beans are a good choice because of their fast maturity and sorghum because of its tolerance to water stress. As the length of rainy period increases, crops such as corn, soybeans, and peanuts become feasible alternatives. Vegetable crops also provide attractive alternatives, although they usually require more investment in terms of labour and cash inputs, and an assured market if the produce is to be sold.

Soil Texture and Topography

Soil texture is directly related to the workability and water-holding capacity of the soil. Light-textured soils are generally associated with a low capacity to hold water, so that residual moisture is quickly depleted, and moisture stress is more likely to occur. On the other hand, the conversion from a puddled to a well-aerated and unsubmerged soil is easier with a light-textured soil because it can be plowed soon after the rice is harvested. Consequently, the choice of crops that can be planted after rice in a light-textured soil is wider. In contrast, the heavy-textured clay soils are difficult to plow and convert from puddled to well-aerated upland soils, but their water-holding capacity is higher, and residual moisture can support growth of upland crops for a longer period. Consequently, in the heavy-textured paddy soil, upland crops grown after rice can be seeded without cultivation, which avoids the difficulty of plowing and maximizes the benefits from residual soil moisture.

Depending upon topography, rice paddies can be classified into those on side slopes, plateaus, plains, and bottom lands (Figure 2.2). Soil topography directly affects water availability. Because water follows the topographic gradients, the plateaus are the first to dry and the bottom lands are the first to be submerged and the last to dry. Consequently, bottom lands are most suited to the rice - rice sequence whereas plateaus and side slopes are more suited to the rice - upland crop patterns. The position of the paddy on the slope may also result in different soil texture in that the bottom lands are usually heavier and the plateaus and side slopes are lighter. The plateaus and the side slopes are more easily drained, less prone to waterlogging, and more suited to upland crops during the drier period of the year.

Market Accessibility

As the intensity of land use is increased and farm products are diversified, farm profitability depends more and more on the efficiency with which products are marketed. Marketability of a product depends on two main factors -- storability and market volume. A crop that can be stored easily for a long period is much easier to market than perishable

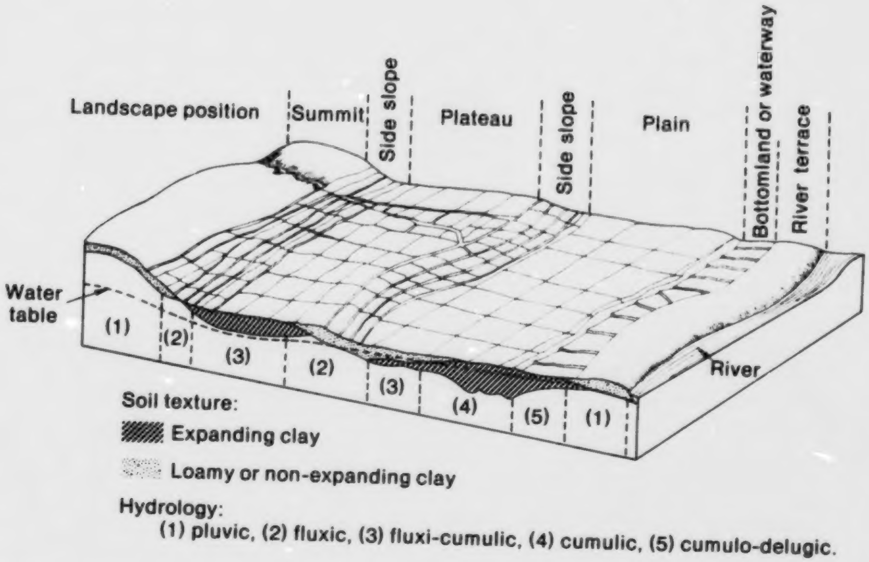
Landscape position
Summit
Side slope
Plateau
Side slope
Plain
Bottomland or waterway
River terrace
Water table
(1)
(2)
(3)
(2)
(3)
(4)
(5)
(1)
River
Soil texture:
▨ Expanding clay
░ Loamy or non-expanding clay
Hydrology:
(1) pluvic, (2) fluxic, (3) fluxi-cumulic, (4) cumulic, (5) cumulo-delugic.

Figure 2.2. Schematic representation of geomorphic and pedologic conditions in Iloilo outreach site (after Raymundo 1976).

products. Food crops that are commonly used by the family have a much bigger market volume and are, therefore, more easily sold. Among the annual crops, the grain crops are the easiest to market whereas the perishable vegetables are the most difficult. Thus, in farms near market centres, vegetable crops with high profit potential are attractive alternatives, but, in remote areas that are far from the market, they must be avoided. Grain crops such as rice, corn, and mung beans, however, can be easily stored or marketed in local outlets and provide better alternatives for farms that are far from market centres.

CHAPTER 3: MULTIPLE CROPPING WITH ANNUAL UPLAND CROPS

The term upland is widely accepted to denote not so much the elevation of the land but rather unsubmerged and well-aerated soils that prevail during the cropping period. It brings to focus the contrast between the submerged soil of the lowland paddy and the "dry" upland soil in which the moisture content is usually below its capacity. There are no levees in upland areas and the standing water, so common in lowland paddies, is absent. The term annual upland crops refers to crops that are grown in upland areas and that mature in less than 12 months.

Annual crops are those in which the life cycle is completed in less than one year and the plants die soon after the fruits have matured. The upland areas are the natural habitat of many annual crop species and, consequently, there is a wide diversity of species that belong to the category of annual upland crops. They can be classified according to their morphology and cultural requirements into four groups (Table 3.1):

a) Grain crops. Dry grain is the primary economic product. Culture is characterized by high density of plants, low labour requirement, low material input, and low, but stable, return per unit area. The major grain crops are cereals (corn, wheat, and sorghum) and legumes (mung beans, soybeans, and peanuts).

b) Vegetable crops. Economic products consist of plant parts that are succulent (i.e., have high water content). Culture is characterized by high input and high profit potential. Some examples are tomatoes, cabbages, and cowpeas.

c) Root crops. Roots are the primary economic product. They are grown over a wide range of environment and cultural practices, resulting in a very wide range of productivity. Some examples are sweet potatoes and cassava.

d) Nonfood crops. Economic products are not used as food but are processed into industrial products. Typical examples are tobacco and cotton.

The harvest area of annual upland crops (Table 3.2) constitutes more than 60% of the cropped area of Asia. The popularity of these crops can be attributed to their short maturity (many annual upland crops mature in less than 140 days) and their morphological diversity. To a farmer, whose resources are limited and whose income is primarily derived from the farm, fast-maturing crops are desirable for their quick return on investment and for their flexibility in adjusting to the changing market and family needs.

The crops that can be grown on an upland area are numerous. There are at least 20 annual food crop species and many more that are used for other purposes (see Table 3.1). Their diversity is useful in satisfying the food requirements of the rural household. Thus, even in areas of predominantly rice or perennial crops, farmers usually maintain

Table 3.1. Characteristics of the most commonly grown annual upland crops in the humid tropics of Asia

Crop name		Planting method	Population[1]	Stature	Plant height[2]	Maturity[3]	Main product
Common	Scientific						
Grain crops							
Corn	*Zea mays*	hills	low	erect	medium	short	dry grain
Sorghum	*Sorghum bicolar*	drill	high	erect	medium	short	dry grain
Wheat	*Triticum vulgare*	drill	high	erect	short	very short	dry grain
Millet	*Setaria italica*	drill	high	erect	short	short	dry grain
Sesame	*Sesamum indicum*	drill	high	erect	short	very short	dry grain
Mung beans	*Vigna radiata*	drill	high	erect	short	very short	dry grain
Soybeans	*Glycine max*	drill	high	erect	short	very short	dry grain
Lentils	*Lentilla lena*	drill	high	erect	short	very short	dry grain
Peanuts	*Arachis hypogaea*	hills	high	erect	short	short	dry grain
Snap beans	*Phaseolus vulgaris*	hills	low	vine	creeping	very short	green pods or dry grain
Vegetable crops							
Green corn	*Zea mays*	hills	low	erect	medium	very short	cob
Cowpeas	*Vigna sinensis*	drill	low	erect	short	very short	pod
Tomatoes	*Lycopersicon esculentum*	trans- planted	low	erect	short	very short	fruit

Table 3.1. (Continued)

Crop name							
Common	Scientific	Planting method	Population[1]	Stature	Plant height[2]	Maturity[3]	Main product
Eggplants	Solanum melongena	trans-planted	low	erect	short	short	fruit
Cucumber	Cucumis sativus	hills	low	vine	creeping	very short	fruit
Cantaloupe	Cucumis melo	hills	low	vine	creeping	very short	fruit
Cabbages	Brassica oleracea	trans-planted	low	erect	short	short	leaves
Root crops							
Sweet potatoes	Ipomoea batatas	cuttings	low	vine	short	short	shoot
Cassava	Manihot esculenta	cuttings	low	erect	medium	long	roots
Taro	Colacasia esculentum	bulbs	low	erect	medium	long	roots
Non-food crops							
Cotton	Gossypium hirsutum	hills	low	erect	short	long	fibre
Tobacco	Nicotiana tabacum	trans-planted	low	erect	medium	long	leaves

[1] Plants per hectare: low <100,000; high >200,000.

[2] In centimetres: short <130; medium 130-200.

[3] Days from planting to harvest: very short <100; short 100-140; long >200.

Table 3.2. Harvest area of some annual upland crops in Asia

Country	Harvest area (1000 ha)				
	Cereals[1]	Legumes	Root crops	Vegetables[2]	Total
Bangladesh	252	327	148	25	752
China	80,561	11,173	15,548	855	108,137
India	65,381	23,587	1257	156	90,381
Indonesia	2550	625	1958	62	5195
Japan	202	118	307	164	791
Korea	648	65	144	77	934
Pakistan	8618	1497	44	neg	10,159
Philippines	3445	70	294	44	3853
Sri Lanka	111	27	224	14	376
Thailand	1248	228	741	81	2298
Total	163,016	37,717	20,665	1478	222,876

[1] Excludes paddy rice.

[2] Includes cabbages, tomatoes, cauliflowers, eggplants, and green beans only.

Source: FAO Yearbook (1978).

some annual upland crops for consumption by the farm family. Another advantage of the diversity among the annual upland crops is the capacity to adjust to a wide range of resource requirements. For example, a family with low labour supply and low capital input might choose to plant a grain crop like corn, which requires less than 50 man-days of labour and less than $140 in material input per hectare (MCEPP 1979). On the other hand, a family with a lot of labour and capital, but with very limited land, could opt for the very intensive crops, such as tomatoes, which require up to 200 man-days of labour and $400 cash input per hectare, but have a potential net income of as much as two to three times that of the grain crops.

With the many fast-maturing annual species that cover a wide range of morphological diversity, multiple cropping has traditionally been, and continues to be, widely practiced in upland areas.

The Traditional Cropping Patterns

With the wide diversity among annual upland crops and the many cropping patterns that can be derived from them, even the traditional patterns are many. They have generally been designed to satisfy as much of the food requirements of the farm household as possible (subsistence-oriented farming) and, consequently, are characterized by the following features:

a) Preference of intercropping. Intercropping offers two important advantages to a subsistence-oriented farm household. First, it enhances the diversity of farm product, a very desirable feature for farms in which a major portion of the product is used directly to satisfy the food requirement of the family. Secondly, intercropping increases the stability of farm productivity so that the yield level, even during bad years, is still high enough to satisfy the minimum food requirement of the family. This important feature of intercropping is shown by two extensive trials on sorghum + pigeon peas (Khrisnamoorthy 1980) and corn + soybeans (Rao et al. 1979) in which the intercrop combinations had a much lower probability of producing a low income relative to their monocrop counterpart (Table 3.3). For example, the probability of net income falling lower than $350/ha is once in every four years for the corn or soybean monocrop but only once in 13 years for the corn + soybean intercropping.

b) Low, but very stable, productivity. Because farm products are used directly to satisfy the food requirements of the household, wide fluctuation in productivity, in which family needs may not be satisfied in some bad years, cannot be tolerated. Hence, the preferred production strategy is one that is very stable in that it is able to satisfy a minimum level of production during disaster years. Unfortunately, this strategy usually has a productivity potential that is also low.

c) Low cash inputs. Purchased farm inputs such as fertilizers and insecticides are seldom used. Most of the inputs are derived from locally produced materials such as organic fertilizers from farm wastes and by-products. Thus, cash expense is minimal and the probability of a negative net income is very low.

d) Use of traditional varieties. In general, traditional varieties are highly tolerant to adverse environmental conditions such as drought, waterlogging, pest attack, and strong winds. They can compete favourably with modern varieties under low management, but are usually considered low yielding because of their generally poor response to high input management.

Table 3.3. Net income, coefficient of variation (c.v.), and probability of net income per hectare falling below $350 for monocrop and intercropping

Cropping pattern	Income		Probability of net income/ha falling below $350
	Net income ($/ha)	c.v. (%)	
Sorghum	361	53	0.48
Pigeon peas	523	47	0.24
Sorghum + pigeon peas	618	35	0.11
Corn	632	65	0.24
Soybeans	506	47	0.26
Corn + soybeans	852	41	0.08

Sources: Rao et al. (1979); Krisnamoorthy (1980).

Technologies for Intensive Cropping

Two major changes have eroded the suitability of the traditional cropping patterns and favoured the use of modern ones. First, advances in agricultural research have produced new crop varieties and new management practices that have greatly improved the productivity and stability of the more intensive patterns. Secondly, and probably more important, farm-to-market roads, communication facilities, and market outlets have been greatly expanded and, thus, many of the constraints that restricted the cropping pattern alternatives of the traditional farm have been relaxed if not altogether eliminated. The subsistence-oriented traditional farm is now rapidly changing to one which is market oriented.

Varietal Improvement

Short growth duration, drought tolerance, and shade tolerance are the three characteristics of crop varieties that could significantly enhance the productivity and stability of intensive cropping patterns.

Breeding for Short Growth Duration. Varieties with short growth duration (fast-maturing) provide several advantages, most important of which is the improvement of productivity per unit time. Another advantage is the added flexibility in fitting together several crops over a limited period of time. Early maturity, however, is generally associated with low yield, because the limited time for vegetative growth is not enough to achieve maximum yield (Yoshida 1977). Thus, many of the newly developed fast-maturing varieties of annual upland crops have slightly lower yields per crop than their slow-maturing counterparts although they are quite comparable in terms of yields per day (Table 3.4).

Breeding for Drought Tolerance. Irrigation water is not as widely used for annual upland crops as for lowland rice. Consequently, upland crop culture is much more dependent upon rainfall and has a higher chance of being exposed to drought. Thus, drought tolerance has always been a very important objective in breeding upland crops.

Breeding for drought tolerance has many difficulties. First, the mechanism for drought tolerance is not well understood in most crops. There are seemingly many ways in which different species cope with water stress. Secondly, it is not easy to initiate and maintain uniformly over the same field the moisture level that is ideal for identifying varietal difference. Finally, there are, at present, no well-accepted and efficient indices with which to separate tolerant from susceptible varieties. Thus, despite the importance attached to drought tolerance for upland crops, not many breeding programs in the tropics are specifically oriented to the improvement of this characteristic.

Fortunately, there are large differences in the degree of tolerance to water stress among the many species of annual upland crops. Sorghum and mung beans are good examples of drought-tolerant species, whereas corn and many of the vegetables are more susceptible to water stress. Multiple cropping technology has used more the variability in drought tolerance among species than that among varieties within a species.

Table 3.4. Relative yields of early-maturing, recommended, and traditional varieties of three annual upland crops

Crop and type of variety	Maturity[1] (days)	Yield	
		t/ha/crop	t/ha/day
Corn (3 trials[2])			
Traditional	95	3.77	0.040
Recommended	98	4.88	0.050
Early-maturing	74	3.53	0.048
Sorghum (7 trials[3])			
Traditional	105	4.10	0.039
Recommended	110	4.46	0.041
Early-maturing	81	3.16	0.039
Cowpeas (4 trials[2])			
Traditional	76	1.44	0.019
Recommended	79	1.92	0.024
Early-maturing	71	1.30	0.018

[1] Days to harvest.
[2] Sources: IRRI (1975, 1977); Carangal et al. (1977).
[3] Source: Gomez (1970).

Breeding for Tolerance to Shade. Tolerance to shade is a fairly new objective for many breeding programs in the region. Monocrops are usually grown in open areas and shade tolerance has not been given much attention. However, with the intensification of land use through intercropping, both of annual and perennial crops, the importance of shade tolerance has increased.

Results of several variety trials of the annual upland crops conducted under shaded and unshaded environments are summarized in Table 3.5. Although the yield of all species tested is reduced by shading, there is a wide range of yield reduction among the species, with the lowest yield reduction exhibited by corn and the highest by sweet potatoes. In 7 of the 22 trials, the correlation between variety yields in shaded and unshaded environments was not significant, indicating that the best variety in the unshaded environment may not be the best under shade.

In 1975, a breeding program was initiated at UPLB to identify varieties of several annual upland crops that are specially adapted to the shaded environment (Table 3.6).

Table 3.5. Yields of some annual upland crops grown in shaded and unshaded conditions in variety trials

Crop	No. of trials	No. of varieties tested	Yield (t/ha)		Yield reduction (%)	No. of trials with insignificant correlation[1]	Source
			Unshaded	Shaded			
Corn	2	96	1.85	1.70	8	0	VSIC 1976, 1977
Sorghum	2	32	2.78	2.12	24	1	VSIC 1976, 1977
Climbing beans	8	643	2.51	1.06	58	3	CIAT 1978; Francis et al. 1978, 1979
Bush beans	3	49	2.24	1.04	54	0	Francis et al. 1978
Mung beans	2	36	0.83	0.31	63	1	Lantican and Catedral 1977; VSIC 1981
Soybeans	1	16	1.02	0.71	30	0	Lantican and Catedral 1977
Sweet potatoes	4	47	16.16	2.62	84	2	VSIC 1977

[1] Between yields of shaded and unshaded conditions.

Table 3.6. Promising annual upland crops for growing under shade

Crop/Variety	Yield[1] (t/ha)	Maturity (days)	Plant height (cm)
Soybeans			
UPL SY-2	1.17	84	87
Williams	1.09	84	84
Kaoshing #3	1.04	81	63
Multivar 80	0.93	85	73
Sorghum			
UPLB SG-5	3.72	90	126
D 67-4	3.67	88	138
CS 108	3.12	90	130
CS 137	3.07	92	123
CS 104	3.05	88	125
Sweet potatoes			
BNAS 51	8.7	90	na
Binicol	5.9	90	na
Catanduanes 3	5.8	90	na
Sinabulu	5.8	90	na
Corn			
Phil. DMR comp. 2	4.92	96	231
BPI Var. 4	4.66	100	212
Phil. DMR comp. 3	4.54	94	239
Cowpeas			
VCS 6-1G	0.70	59	101
TVU#3296	0.59	59	142
VCS 6-12W	0.58	62	142
Mung beans			
CES 2V-10	0.50	na	na
CES 26-1	0.43	na	na
CES 2F-8	0.43	na	na
CES 3N-17	0.39	na	na
Peanuts			
Acc. #1	3.10	67	40
Acc. #183	2.29	63	38
Acc. #178	2.14	63	50
Acc. #197	2.00	63	56

[1] Yield is based on total root weight. All entries were harvested 90 days after planting.

Sources: Buajarem (1978); VSIC (1976, 1977, 1978).

Intercropping

Research into the technology of intercropping is directed generally at identifying those crop combinations and associated management practices that maximize productivity per unit area of land. The index commonly used to evaluate an intercropping technology is the land equivalent ratio (LER), which is defined as:

$$\text{LER} = \sum_{i-1}^{n} (X_i/Y_i) \qquad [3.1]$$

where X_i is the yield of crop *i* in intercropping and Y_i is the yield of crop *i* in pure stand. The LER index essentially compares productivity in intercropping with that in the monocrop, with high values of LER indicating the advantage of intercropping.

To maximize the benefits from intercropping, the following guidelines should be used in designing cropping patterns.

Minimize Competition. Crops and management practices should be selected such that the peak demand for limited environmental resources in one crop does not coincide with that of the other. This is usually accomplished by using species with very different periods for maturing in the intercropping pattern. For example, sugarcane, which takes about one year to mature[2], needs about 2.0 to 2.5 months from the time of planting to the time when leaves from adjacent rows overlap (Mendoza and Rosario 1979). During the preoverlapping period, solar energy either goes to waste or is used by weeds growing between the rows of sugarcane. Fast-growing legumes like mung beans, the seedlings of which mature quickly, are ideal crops to grow between rows of developing sugarcane plants. The yield reduction in sugarcane due to mung-bean intercropping is small but that for mung beans can be as high as 82% (Table 3.7). Yield reduction in mung beans, however, can be minimized with the use of widely spaced double rows in sugarcane.

Minimize Pest Damage. Crop combinations should be selected such that the presence of one species results in a reduction of pest incidence in another. For example, Buranday and Raros (1975) have shown that *Plutella* infestation in cabbages is reduced by the presence of tomatoes as an intercrop. Other examples of reduced pest incidence resulting from intercropping are shown in Table 3.8.

Maximize Complementary Effects. Crop associations should be used in which the species are mutually beneficial to each other. The grass + legume intercropping is a good combination for this purpose. Grasses usually grow tall and slim, whereas legumes are usually low and creeping. Legumes are usually susceptible to waterlogging and low pH,

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[2] Depending upon the variety used, sugarcane matures in between 11 and 16 months in the humid tropics of Asia. This species is, thus, considered as an annual rather than a perennial crop.

Table 3.7. Yields of sugarcane and mung beans in pure stand and in intercropping

Treatment[1]				Yield (t/ha)[2]		
Code	Row combination of sugarcane	Distance between row combination (m)	Days to cone overlap	Sugarcane	Mung beans	Land equivalent ratio (LER)
S_1	single row	1.0	63	23.3	0.80	1.34
S_2	double row	1.0	63	24.7	0.67	1.34
S_3	quadruple row	1.0	63	16.8	0.41	0.90
S_4	double row	1.5	84	16.9	0.52	0.95
S_5	quadruple row	1.5	84	14.0	0.42	0.78
S_6	double row	2.0	105	21.1	1.07	1.35
S_7	quadruple row	2.0	105	20.3	0.79	1.20
S_8	double row	2.0	105	19.5	1.05	1.29
S_9	quadruple row	2.0	105	16.2	0.77	1.05
S_{10}	pure stand	-	63	23.6	2.25	1.00

[1] Within a row combination, distance between rows is 0.5 m except for S_8 and S_9 where it is 1.0 m. Legumes are grown between row combinations in single rows for S_1 and S_3, in double rows for S_4 to S_6, and in triple rows for S_7 and S_9.

[2] Sugar for sugarcane and shelled grain for mung beans.

Source: Mendoza (1979).

Table 3.8. Examples of some intercropping patterns that have resulted in pest incidence lower than that in pure stand

Intercropping pattern	Pest affected	Source
Cabbages + tomatoes	Plutella	Buranday and Raros 1975
Corn + mung beans	Weeds	Bantilan et al. 1974
Corn + peanuts	Corn borer	IRRI 1975
Cress + grass	Phytum irregulare	Burdon and Chilvers 1976
Sesame + sorghum	Pyralid welburn	Litsinger and Moody 1976
Cotton + corn	Heliotes	Pearson 1958

whereas grasses are more tolerant. Grasses are heavy users of nitrogen, whereas legumes can fix this element from the atmosphere. A specific example is the corn + mung-bean intercropping. Corn is usually planted in rows 75 to 100 cm apart and mung beans are sown between these rows. Mung beans mature in about 70 days whereas corn takes 110 to 130 days. The vigorous mung-bean seedlings cover the ground soon after seeding, resulting in better competition against weeds and more efficient use of solar energy and carbon dioxide. These advantages are confirmed by the

Table 3.9. Yield and gross return from intercropping corn and mung beans

Cropping pattern	Unweeded	Hand-weeded
Corn yield (t/ha)		
Corn	2.6	4.1
Corn + mung beans	3.1	3.3
Mung bean yield (t/ha)		
Mung beans	1.2	1.3
Corn + mung beans	0.6	0.7
Gross return ($/ha)		
Corn	400	630
Mung beans	708	777
Corn + mung beans	462	500
Land equivalent ratio (LER)	1.7	1.3

Source: IRRI (1973).

results of experiments conducted by Banta and Harwood (1975) in which they compared the performance of corn + mung-bean intercropping with that of the corresponding pure stands (Table 3.9). The yield of corn in the intercropping was higher than that in the pure stand when the field was not weeded, illustrating the effectiveness of the legume intercrop in reducing the incidence of weeds which could potentially reduce corn yield.

Maximize Effective Vegetative Ground Cover. Ground cover is very important in reducing soil erosion, especially under intense rainfall in the humid tropics of Asia. The rate with which crop vegetation can cover the cultivated land increases with intercropping, resulting in a significant reduction in soil erosion. For example, cassava as a monocrop takes 63 days to provide a 50% ground cover as compared to only 50 days for a cassava + corn intercropping (Lal 1980). Thus, by intercropping cassava with corn, soil loss was reduced by 38% in an area with 15% slope (Aina et al. 1977).

The LER values for various combinations of intercrops and management practices are shown in Table 3.10. The LER values ranged from 0.86 to 2.20, with 97% of all values exceeding 1.0, indicating that, in spite of the competition among species, intercropping is almost always more productive than monocropping. Also, for every intercrop combination, a specific management practice makes the combination more productive than monocropping.

Some Important Cropping Patterns

With the variety of annual upland crops, the alternative cropping patterns in upland areas are more numerous and more diverse than those for the lowland rice paddies (Table 3.11). These patterns can be classified into two groups; those with fast-maturing annuals, and those with slow-maturing annuals.

Cropping Pattern with Fast-Maturing Annuals

With the short life cycle of the component crops (less than four months), sequential cropping is commonly used to maintain crop production all year long. By careful selection of component crops from a widely divergent group of fast-maturing species, a farmer can grow different crops at different times of the year to cope with cyclical fluctuations in the climatic and economic environments of the farm.

Among species of annual upland crops, the difference in their abilities to adapt to the cyclical fluctuations in climate is illustrated by the results of an experiment conducted by IRRI at Cale, Batangas, Philippines, involving eight fast-maturing annuals (IRRI 1975). Cale is a farming community characterized by a rainfall exceeding 2000 mm/year (Figure 3.1a); a topography that is mildly rolling; a soil pH that ranges from 4.9 to 6.2; a soil texture that ranges from sandy loam to clay loam; a good internal drainage; and a high tillage capability. Crop adaptability was evaluated by planting each species every month. A planting in which the crop yielded at least

Table 3.10. Land equivalent ratios (LER) of various types of intercrop combinations under different levels of management

Intercropping	Test factors	Treatments (No.)	LER		Source
			Mean	Range	
Corn + rice	spacing nitrogen varieties	53	1.17	0.90-1.52	IRRI 1975, 1976
Corn + legumes	spacing nitrogen varieties location species	127	1.37	0.86-2.12	Syarifuddin et al. 1974; IRRI 1975; Pookpakdi 1975; Carandang 1979; Rao et al. 1979
Sorghum + others	spacing species	16	1.15	0.90-1.52	Baker and Norman 1975; IRRI 1975, 1976
Wheat + others	species spacing	18	1.20	0.86-1.57	Hoque et al. 1978
Cassava + others	species	4	1.68	1.17-2.20	Moreno and Hart 1979
Sugarcane + legumes	spacing species	18	1.40	0.90-2.06	Mendoza 1979

Table 3.11. Cropping patterns of annual upland crops grown at various locations in the humid tropics

Location	Annual rainfall		Cropping Pattern	Source
	Total (mm)	Distribution		
Northeast Thailand	1300	uneven	Cassava + legume Kenaf + legume Legume - legume Legume - cereal	KKU-FORD 1976
Capiz, Philippines	2000	pronounced dry season	Cassava + corn Corn - sweet potatoes - corn Rice - sweet potatoes - mung beans Sugarcane + mung beans	Jeresa et al. 1979
Lampung, Indonesia	2500	even	Cassava + (rice + corn - peanuts) Rice + corn - corn Rice + corn - rice - beans	Suryatna et al. 1976
Turrialba, Costa Rica	2500	even	Cassava + beans Cassava + corn Cassava + sweet potatoes + beans	Moreno and Hart 1979
Pundi Bhundi, Nepal	3840	pronounced dry season	Corn/fingermillet - potatoes Corn/fingermillet - wheat Corn/fingermillet - mustard	Malla et al. 1980

one half of its potential yield is considered a feasible planting date for that crop (Figure 3.1b). Corn and cowpeas, with the widest range of adaptability and feasible planting dates of eight and ten months, respectively, can stand both the excess water during the heavy rainfall months and the lack of water during the dry months at the tail end of the monsoon season. Rice, however, with its heavy requirement for water can be planted only during the early part of the monsoon season (April to June). Sorghum, mungbeans, peanuts, and soybeans -- species that are known for their tolerance to drought and their susceptibility to grain

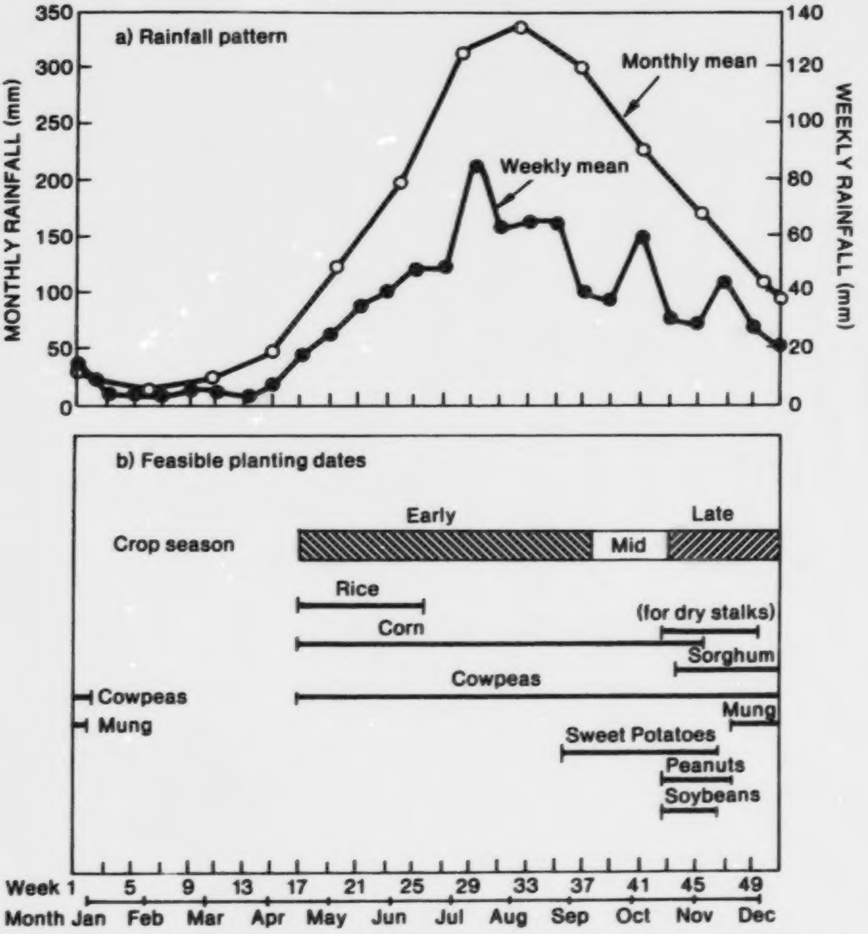

Figure 3.1. Rainfall pattern (a) and feasible planting dates (b) for various upland crops in Cale, Batangas, Philippines (after IRRI 1977).

deterioration -- can be planted only towards the tail end of the monsoon season so that their grain-filling stages coincide with the drier months of the year. Finally, sweet potatoes, the only root crop tested, can be planted only during the mid-season (September to October) and will tolerate heavy rain in the first 60 days of growth but will rot if not harvested early (within 120 days) during the wet period.

In the sequential cropping patterns designed and tested for Cale (Table 3.12), rice fits well as the first crop. Seeds are sown after the first monsoon rains, and the grain-filling stage, the most sensitive to water stress, coincides with the peak rainy months of the

Table 3.12. Yields (t/ha) of sequential cropping patterns evaluated in Cale, Batangas, Philippines, with low inputs in 1974-75 and high inputs in 1975-76 crop seasons

Cropping pattern	Low inputs			High inputs		
	Crop 1	Crop 2	Crop 3	Crop 1	Crop 2	Crop 3
Rice - soybeans	1.40	0.95		3.28	0.67	
Rice - peanuts	1.40	0.80		2.96	1.75	
Rice - field corn	1.40	1.53		3.09	4.10	
Rice - mung beans	1.40	0.35		3.15	0.60	
Rice - sorghum - sorghum (ratoon)	1.40	2.46	0.98	3.00	3.87	0.64
Rice - green corn - mung beans	-[1]	-	-	3.02	38.7[2]	0.77
Green corn - field corn - mung beans	-	-	-	34.9[2]	3.86	0.59

[1] Not tested.
[2] In thousand marketable ears per hectare.
Source: IRRI (1977).

year. On the other hand, mung beans, with their short maturity and tolerance to drought, performed well in the late season when planted as the last crop in a three-crop sequential pattern. Finally, sorghum, which can be ratooned, showed good promise as a second and third crop after rice.

Although sequential cropping patterns are most commonly used when fast-maturing annuals are involved, some intercroppings are also used, of which the two most commonly used are rice + corn and corn + grain legume. The rice + corn intercropping is usually grown during the rainy months because both crops can tolerate heavy rainfall even at harvest time. The corn + grain legume intercropping is usually grown as a second crop, so that its harvesting will coincide with the tail end of the monsoon and the grain legume will not be exposed to heavy rains at maturity.

Production, cost, and returns of cropping patterns involving fast-maturing annuals are shown in the first four rows of Table 3.13. The cereals and grain legumes are most commonly used because they are important in the household diet, easily stored even at ordinary room temperature, and easy to market even in remote areas. Compared to the patterns used in the lowland rice paddies (see Table 2.12), the net returns from cropping patterns involving annual upland crops are generally lower. In the humid tropics, lowland rice is generally more productive and more profitable than the annual upland grain crops.

Cropping Patterns with Long-Maturing Annuals

Several important annual crops with life cycles longer than six months are cassava, kenaf, castor beans, and sugarcane. These species have large canopies and are planted in wider rows relative to the fast-maturing annuals. They are slow-growing at the seedling stage and usually take more than two months to completely shade the space between rows. Cropping patterns involving these slow-maturing annuals have two distinguishing features: First, that intercropping is the predominant component of the cropping pattern; and secondly, that the slow-maturing annual is the dominant crop in the pattern.

Intercropping: An Important Component of the Pattern. Because slow-maturing annuals occupy the land for most of the growing season, sequential cropping is not practicable so intercropping is most suited. The fast-maturing annuals such as corn, rice, and mung beans are the most commonly used intercrops. The usual practice is to plant both crops simultaneously such that the fast-maturing annuals can be harvested before the slow-maturing species have completely shaded the ground. Because the slow-maturing annuals are usually planted at the start of the rainy season, the fast-maturing annuals should be selected to fit the expected rainfall pattern of the area. Thus, in Indonesia where rainfall is high, rice and corn are the major intercrops grown during the seedling stage of cassava (Table 3.14). These crops are tolerant to the expected heavy rainfall at harvest. On the other hand, in Northeast Thailand, where rainfall is low, legumes are more commonly intercropped either with cassava or with kenaf (TDA 1980).

When the slow-maturing annual starts to mature, its leaf area index decreases and more sunshine penetrates its canopy. At this stage, another fast-maturing annual can be planted as a second intercrop

Table 3.13. Production, cost, and returns (per ha/year) for some commonly used cropping patterns involving annual upland crops

Cropping pattern	Country/year	No. of trials	Production t/ha	Production $/ha	Variable cost ($/ha)	Net return ($/ha)	Source
Corn - corn	Philippines, 1980	7	6.40	771	296	475	Quisumbing et al. 1980
Corn - mung beans	Philippines, 1980	8	3.39	606	301	305	Quisumbing et al. 1980
Legume - legume	Thailand, 1978	9	1.48	337	137	199	Chandrapanya 1980
Corn + rice - corn/peanuts	Indonesia, 1977	4	3.95	583	396	187	Imtiaz et al. 1978
Cassava	Thailand, 1979	6	25.10	1092	na	na	TDA 1980
Cassava + grain legume	Thailand, 1979	6	20.35	1036	na	na	TDA 1980
Cassava + (corn + rice - peanut - ricebean)	Indonesia, 1977	4	25.69	1158	762	396	Effendi and McIntosh 1978

Table 3.14. Management of two cropping patterns commonly used in upland areas of Indonesia

Cropping Pattern	Crop	Spacing (m)	Population per ha (1000 plants)
Oct Nov Dec Jan Feb Mar Apr May Jun Jul Aug Sep			
├─ Corn ─┤	corn	2.0 x 0.4	25
├─ Upland rice ─┤	upland rice	0.4 x 0.2	125
├──── Cassava ────┤	cassava	4.0 x 0.4	6
├─ Corn ─┤	corn	2.0 x 0.4	25
├─ Upland rice ─┤	upland rice	0.4 x 0.2	167
├──── Cassava ────┤	cassava	4.0 x 0.4	6
├─ Peanuts ─┤ ├─ Ricebeans ─┤	peanuts	0.2 x 0.2	250
	ricebeans	0.4 x 0.2	250

usually in the late season when rainfall is decreasing. Fast-maturing legumes that are tolerant to drought and require drier weather at maturity are ideal intercrops. This is the case in Indonesia where the legume intercrops are planted as the cassava matures (see Table 3.14).

Slow-Maturing Annual as the Dominant Crop. The slow-maturing annual is usually the major source of income for the farmer whereas the fast-maturing intercrop is used mainly to supplement the food needs of the farm household while waiting for the main crop. For example, in a sugarcane + mung-bean intercropping, more than 80% of the gross value of the product is contributed by sugarcane, the slow-maturing intercrop (see Table 3.7). It is essential, therefore, that productivity of the slow-maturing main crop is neither disrupted, nor substantially reduced, by the fast-maturing intercrop.

Determinants of Cropping Patterns

The three most important determinants of cropping pattern in upland areas are rainfall, soil characteristics, and access to market.

Rainfall

With the limited availability of irrigation in upland areas, rainfall becomes the primary source of water and its influence on the feasibility of alternative cropping patterns is much more pronounced than that in the lowland rice paddies. Rainfall intensity and distribution affects soil workability, crop growth and development, and the maturing fruit.

Effect on Soil Workability. Plowing or row cultivation in upland areas can be used only when the soil moisture level is lower than field capacity. Most upland soils, therefore, cannot be plowed or cultivated soon after a heavy rain. Heavier soil with high water-holding capacity takes longer to dry than lighter soil. Thus, land preparation in heavy-textured soils becomes a problem during months of high rainfall. Large tractors are especially handicapped during the wet months because they cannot be moved in the wet field. Under this condition, the lighter animal-drawn cultivators are more versatile.

Land preparation cannot always be completed during the dry months but may have to wait for the first few rains. After the first plowing, especially when the soil is very dry, the large soil clods will not separate to form well-pulverized seed beds unless they are first saturated with water before the next plowing or harrowing. The ideal rainfall pattern during land preparation is one that occurs in cycles of several days to allow for the alternate wetting and drying of the furrow slice. A series of heavy rains does not allow enough time for the soil to dry. Thus, land preparation, which may be difficult for heavy soils during the mid-season planting, becomes easier during the start or the tail end of the rainy season.

Effect on Growth and Development. For annual upland crops in which the life cycle is short and the growth and development are very rapid, the early-seedling and fruit-development stages are the most vulnerable to water stress. At the early-seedling stage, the plant is usually very fragile and water must be available if it is to survive. Fortunately, water availability during the short seedling stage can be assured by planting soon after a good rain. For heavy soils with good water-holding capacity, adequate soil moisture at planting can last more than one week without additional rain.

The fruit-development stage starts from pollination and ends when the fruits are biologically mature. For the grain crops, biological maturity is usually reached within 25 days after pollination. At this stage, the crop needs water to support the very rapid rate at which photosynthates are stored in the fruit, and the availability of water can spell the difference in yield and, thus, between economic success or failure.

There is a wide range of water requirement among the many upland crop species. Considering that the rainfall pattern, and consequently water availability, follows a cyclical pattern within a 12-month period, the cropping patterns in the humid tropics of Asia usually follow a sequential pattern in which different species are grown at different times of the year (see Figure 3.1). For example, sorghum and mung beans, two species with good drought tolerance, are usually grown at the tail end of the monsoon season, whereas rice, a crop that requires more water, is planted at the early monsoon season so that its growing period coincides with the high rainfall month.

Effect on Maturing Fruit. For the annual grain crops, it takes about 30 days from biological maturity to the time the crop is ready for harvest. This stage is usually termed the grain-drying period, during which the fully developed grains reduce their moisture content from more than 40% to less than 20%. During that period, many are susceptible to grain weathering, i.e., the rotting or germination of the maturing grains under consistent rainfalls. Thus, for many grain crops, it is essential that the grain-filling stage coincides with a dry period during which rainfall is low and cloud cover is sparse. For example, sorghum, mung beans, soybeans, and peanuts, each known for their susceptibility to grain weathering, cannot be planted during the early monsoon season or the fruits would mature during the peak rainy months. Instead, their planting dates should be in the late season to allow fruiting to coincide with the dry months. Such crops as corn and green cowpeas, the fruits of which are not adversely affected by heavy rainfall, can be planted even during the early season and, therefore, have a wider range of feasible planting dates (see Figure 3.1).

Soil Characteristics

The importance of soil as a determinant of cropping pattern for annual crops in upland areas is highlighted by several factors. First, because they mature very quickly, there is a fast succession of annual crops in cropping patterns of upland areas. As a result, the soil is frequently cultivated, usually when vegetative cover is absent or very sparse, and is very much exposed to soil erosion. Secondly, annual upland crops vary widely in their ability to conserve soil fertility. Cereal grasses are usually very heavy users of soil nutrients whereas legumes are not. By virtue of their ability to fix nitrogen, some legumes improve soil fertility, as illustrated by green manuring. Thirdly, soil texture greatly influences the ease with which the land can be prepared for planting; and lastly, the produce of some upland crops (such as peanuts and root crops) are located underground such that their development and harvesting are facilitated in light-textured soil.

The cropping patterns for the annual upland crops, therefore, should satisfy the following four guidelines.

First, to minimize erosion of slopes, the soil should not be left bare of vegetation. Intercropping, relay cropping, ratooning, minimum tillage, and mulching are some of the techniques that can be employed.

Second, to retain soil fertility with crops that heavily deplete soil nutrients, such as grasses and root crops, sequential cropping or intercropping with the nitrogen-fixing legumes should be used occasionally.

Third, where land preparation is difficult because of soil texture or heavy rainfall, those fast-maturing crops that require constant land preparation and cultivation should be avoided. More favourable are the slower-maturing crops such as cassava, pigeon peas, or those that can be ratooned, such as sorghum or sugarcane.

Fourth, crops such as peanuts, cassava, and sweet potatoes, with underground produce, should be grown only on light-textured soils.

Market Accessibility

The influence of market accessibility on feasible cropping patterns for annual crops in upland areas is very similar to that for lowland rice paddies discussed in Chapter 2. There are two additional considerations.

First, upland areas do not, in general, have as good access to market as do lowland rice paddies. Consequently, marketing farm products is not as easy and the production of bulky and perishable commodities, such as leafy vegetables, is usually limited to that consumed by the immediate family members or neighbours. In contrast, the dry grains of cereals and of field legumes are easy to store, are consumed in large quantities, and have high market demand. These crops, therefore, form the more predominant components of the upland cropping patterns.

Secondly, although upland culture is the natural environment for most crops so that the diversity of products can be great, yet only a few of these can readily be sold in the market.

Because of these market constraints, the combination of grasses and legumes, either as sequential crops or as intercrops, strongly predominates on those farms not easily accessible by roads.

Other crops are included in the pattern primarily to satisfy the food requirement of the farm household. On the other hand, the more intensive and more profitable vegetable crops become more important on farms near population centres, where market access is excellent and where land resources are more limiting.

CHAPTER 4: MULTIPLE CROPPING WITH PERENNIAL UPLAND CROPS

The life cycle of perennial crops spans a period much longer than one year. In fruit trees, for example, flowering followed by fruiting occurs several years after planting. Vegetative growth lasts for many years. Some of the perennial crops important in Southeast Asia and their morphological characteristics are presented in Table 4.1.

Although perennial crops occupy less than five percent of the cropped areas in Asia, they account for a substantial portion of the cropped areas of Sri Lanka, Malaysia, Philippines, Indonesia, and Thailand (Table 4.2). Perennial crops have several attractive features. First, the maintenance of an established plantation is easy and inexpensive, and productivity and potential income are usually high (Table 4.3). Secondly, with the long life cycle of perennial crops, the soil is almost always under vegetation. Thus, erosion is greatly reduced, if not totally elimated, and soil conservation is enhanced.

With the wide spacing of plantings used for many perennial crops (see Table 4.1), only a small portion of the ground is shaded by the young seedlings, and other crops, usually the fast-maturing annuals, are grown as intercrops. This intercropping has several advantages: First, the bare ground is quickly covered resulting in the reduction of soil erosion and weed growth; secondly, the fast-maturing annuals provide income to the farm household during the unproductive stage of the slow-maturing perennials; and thirdly, the care given to the annuals also benefits the perennial crop.

Perennial crops vary greatly in their morphology and their resource requirements (see Tables 4.1 and 4.3) from a small pineapple plant to a large coconut tree. Some species such as cacao, coffee, and black pepper require much shade and, consequently, have long been intercropped with the tall, sunshine-loving species such as coconut.

The Traditional Cropping Patterns

The traditional culture of perennial crops can be divided into two main categories: the subsistence farm in which a small portion of the land is planted with a highly diverse mixture of perennial crops; and the large plantation in which large tracts of land are given over to a single species.

The Subsistence Farm

On subsistence farms, where production seldom exceeds the needs of the farm household, perennial crops are grown traditionally for the

Table 4.1. Morphological characteristics and productivity of selected perennial crops in the humid tropics of Asia

Crop	Planting material	Height at maturity (m)	Planting to first harvest (yr)	Length of productive life	Spacing of planting (m)	Economic product	Peak production		Source
							Age (yr)	Yield (t/ha)	
Cacao	seedlings	6-8	7	long[1]	12	dry seeds	10-15	1.30	Bates 1957; Williams 1975
Bananas	suckers	2-6	1	medium	10-15	ripe fruit	2	20	Bates 1957; Williams 1975
Pineapples	slips or suckers	0.5	1.5	short	0.25	ripe fruit	1.5	35	PCARR 1976a
Rubber	seedlings	24-40	4	medium	20-25	dry rubber	5-8	2.45	PCARR 1976b
Abaca	suckers	4-9	2	long	4-9	fibre	4-10	0.75	PCARR 1977a
Papayas	seedlings	5-7	1-2	medium	4-9	ripe fruit	4-5	7-8	PCARR 1977c
Coffee	seedlings	9	3	long	6-9	dried beans	6-8	0.6	PCARR 1977b
Coconuts	seedlings	20-25	5	long	60-90	nuts	15-30	4-5	PCARR 1975
Mangoes	seedlings	15-30	6	long	70-100	ripe fruit	6-13	21	PCARR 1978a

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[1] Short, <5 years; medium, 5-15 years; and long, >15 years.

Table 4.2. Area under perennial crops in some countries of Asia

Country	Area (1000 ha)	Percentage of cropped area (%)
Bangladesh	212	2.3
Burma	485	4.8
China	950	0.9
India	4100	2.4
Indonesia	2200	12.8
Japan	604	12.1
Malaysia	3330	51.4
Pakistan	260	1.3
Philippines	2850	35.2
Sri Lanka	1122	52.6
Thailand	1900	10.8
TOTAL	18,013	4.8

Source: FAO (1979).

primary purpose of increasing the diversity and stability of food production. Assorted perennials are grown simultaneously, usually planted around the house or farmyard. They contribute to the improvement of the shelter and privacy, and add quality to the diet of the farm family (Harwood and Price 1976).

In terms of stability, the deep-rooted and well-established large trees offer an effective buffer against the ill effects of extreme environment. Whereas unusually wet or dry years drastically affect the productivity of annual crops, well-established perennial trees can more easily survive these stresses with minimal effect on their subsequent productivity. During the lean years, therefore, the perennial crops usually bear a larger share in supplying the food requirements of the farm family.

The Large Plantation

The ease with which a single established perennial crop can be managed, the stability of its production, and the attractiveness of its profit potential have all resulted in the establishment of many large specialized plantations. They are usually characterized by the following features: they occupy very large tracts of land; they are located in sparsely populated areas where land is readily available at a reasonable cost; and they are highly integrated to include not only production but also transportation, processing, and marketing. Some typical examples of these farms are banana, coffee, tea, and pineapple plantations.

Table 4.3. Cost and returns of some perennial crops, by their growth stages

			Cost and return ($/ha/yr)			
Crop	Growth stage[1]	No. of years	Labour[2]	Materials[3]	Gross[4]	Net
Rubber	Establishment	1	256	116	0	-372
	Pre-production	5	39	33	0	-72
	Early production	3	136	67	360	157
	Peak production	40	136	40	604	428
	Average		129	43	515	344
Coffee	Establishment	1	275	288	0	-563
	Pre-production	1	37	167	0	-204
	Early production	4	51	279	610	280
	Peak production	14	53	279	1557	1225
	Average		63	273	1212	876
Coconuts	Establishment	1	252	132	0	-384
	Pre-production	3	30	68	0	-98
	Early production	10	44	140	469	285
	Peak production	46	51	191	1144	902
	Average		52	175	955	728
Papayas	Establishment	1	192	309	640	139
	Early production	1	256	669	3413	2488
	Peak production	5	305	896	4053	2852
	Average		282	780	3474	2412

[1] Establishment starts at land clearing up to one year after planting.
[2] Computed at $1.33/man- or animal-day.
[3] Excluding heavy equipment, land, and interest on capital.
[4] Rubber at $0.29/kg of cuplumps; coffee at $0.80/kg of beans; coconuts at $0.08/nut; papayas at $0.13/fruit.

Sources: PCARR (1975, 1976b, 1977b, c).

The Multiple-Cropping Patterns

Coconuts are one of the most important perennial crops in the humid tropics of Asia (Table 4.4). In the Philippines, they are the most important agricultural export, occupying 76% of the area of perennial crops, and more than 30% of the total cropped area. Because of their importance both economically and in research activities, this section focuses primarily on coconut intercropping.

Table 4.4. Estimated areas of coconut production in six countries in Asia

Country	Year	Area of coconuts (1000 ha)	 As percentage of perennial crops (%)
Philippines	1972	2125	76
India	1975	1116	27
Indonesia	1971	1200	23
Sri Lanka	1971	466	42
Malaysia	1971	532	16
Thailand	1971	165	9

Source: FAO (1979).

Use of Land and Solar Energy

Although plant spacing for coconut palms ranges from 7 x 7 to 10 x 10 m/plant, the effective root zone of a mature palm is confined mainly within a two-metre radius around its base (Kushwah et al. 1973; Creencia 1978). The top 10 cm of soil is practically devoid of functional roots and more than 80% of the roots are found between 30 and 130 cm in depth (Nelliat et al. 1974). Using a two-metre radius as the effective root zone of a coconut palm, Creencia (1978) estimated that only 12.6% of the total surface area is effectively used by a pure stand of coconut palms planted at 10 x 10 m.

Interception of solar energy by coconut palms varies considerably with the age of the tree (Figure 4.1). Interception is minimal at the early stages when the seedlings are still small, increases rapidly and reaches the maximum at the early productive stage, and then gradually decreases with the increasing age of the trees (Nelliat et al. 1974). The amount of solar energy received by crops under the coconut canopy ranges from 88 to 43% of normal sunlight (Lopez 1974; Sajise and Lales 1974; Diaz 1976).

Productivity

With their long life cycle and high annual productivity, coconuts are usually considered as a most valuable crop, and productivity must not be significantly reduced by intercropping. Fortunately, intercropping has usually resulted in an increase, rather than a decrease, in the nut yield (Table 4.5).

The beneficial effect of intercropping on coconuts is attributed to several factors. First, cultivation between trees, which is not usually done in pure stands but is necessary in the culture of the intercrop, improves the yield of coconuts (Dolar 1961; Félizardo 1972). Secondly, the fertilizer applied to the intercrop also benefits the perennial crops (Dolar 1961). Although the benefits from intercropping are primarily associated with inadequate fertilization and cultivation

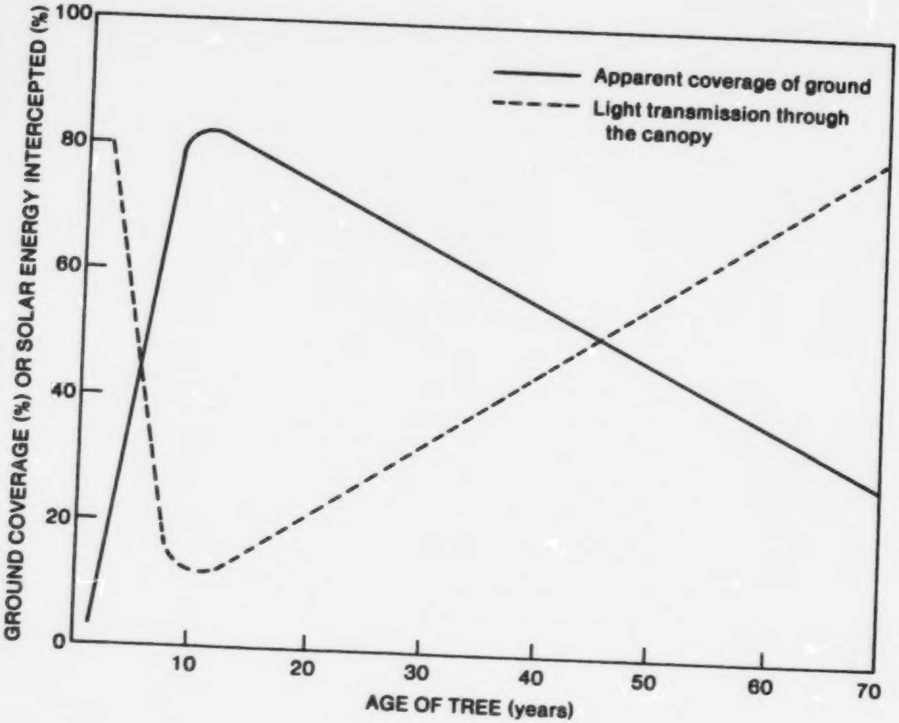

Figure 4.1. Apparent coverage of ground by coconut canopies, as affected by age of the tree (after Nelliat et al. 1974).

Table 4.5. Effects of different intercroppings on the productivity of coconut palms

Intercrop	Coconut yield		Source
	Nuts/tree	% of pure stand	
Cacao	na	130	Ramadasan et al. 1978
Cacao	90	150	Creencia 1978
Tapilan	51	113	Varghese et al. 1978
Elephant yams	59	131	Varghese et al. 1978
Elephant yams	59	151	Menon and Nayer 1978
Cassava	49	126	Menon and Nayer 1978

Table 4.6. Yield of some crops that have performed well under shade

Crop	Yield	
	Under shade (t/ha)	Percentage of normal (%)
Taro[1]	5.48	367
Arrowroot[1]	8.72	68
Ramie[1]	0.16	135
Sunflowers[1]	0.63	95
Mung beans[1]	0.58	85
Corn[2]	2.54	67
Sorghum[2]	1.67	57
Mung beans[2]	0.37	32
Soybeans[2]	0.71	70
Sweet potatoes[2]	2.57	16
Sweet potatoes[3]	2.45	44
Cassava[4]	7.66	29

[1] Source: Carandang (1979).
[2] Source: VSIC (1979).
[3] Source: Cuevas (1978).
[4] Source: Navarez (1976).

given to the coconut monocrop, it is also true that coconut farms in Asia are universally characterized by inadequate fertilizer and cultivation practices (Ilag 1960).

Shading from coconut palms seems to play a major role in determining the productivity of the intercrop in the lower canopy. Although most of the annual grain crops, such as corn and sorghum, show substantial yield reduction when grown under shade, there are several shade-requiring species such as gabi and ramie that yield more under shade (Table 4.6). This beneficial effect of shading is the major reason for the wide cultivation of shade-requiring perennial species, such as cacao and coffee, under coconut palms.

Some Important Intercrops

Both annual and perennial species are commonly intercropped with coconut palms. The annuals are generally planted at the coconuts' seedling stage when the sunshine going through the canopy is enough to satisfy the high energy requirement of the intercropped annuals. While the young coconut palms are still unproductive, the fast-maturing annuals are the main source of farm productivity. In the Philippines, of the 26 species of annual crops commonly grown under coconuts (Cuevas et al. 1974), the most common ones are corn, cassava, sweet potatoes, taro, and peanuts. The perennial crops that are usually planted under coconuts are those that require shade or that can tolerate low solar energy. The most commonly used perennial crops are bananas, pineapples, coffee, lanzones, and cacao in the Philippines and Malaysia (Cuevas et al. 1974; Denamany et al. 1979) and cacao, cinnamon, nutmeg, cloves, and black pepper in India (Nelliat et al. 1974). These crops are generally grown at the bearing stage of coconuts when the palms are able to provide enough shade for the proper development of the intercrop. The primary aim of growing annual intercrops is, thus, to support the farm family while the main crop is still unproductive, whereas that for the perennial intercrop is to increase the efficiency of land use during the most productive years of the main crop.

Determinants of Cropping Patterns

Rainfall, soil characteristics, and access to market are also important determinants of cropping patterns involving perennials. These determinants have been discussed in Chapters 2 and 3, so this section focuses mainly on the degree of shading, a major determinant of cropping patterns in perennial crops. Once the slow-maturing perennial crops are planted and have grown and developed, the shade provided by their canopy becomes permanent in the landscape and should be treated as a factor beyond the farmers' control.

Based on the amount of solar energy intercepted by the tall canopy, the life cycle of the perennial crop can be divided into three stages: First, the preflowering stage, which begins at planting and continues up to first flowering; secondly, the reproductive stage, which begins at first flowering and continues up to the end of peak productivity; and thirdly, the stage of senescence, in which productivity declines. Light interception by the perennial canopy is maximum during its reproductive stage, minimum during the early preflowering stage, and intermediate during senescence (see Figure 4.1).

The Preflowering Stage

During the preflowering stage, the perennial canopy is not fully developed and intercepts only a small fraction of the solar energy. The sunshine that penetrates the perenial canopy is enough to support many intercrops.

Intercropping at the preflowering stage is very attractive. First, the main crop is still unproductive and an additional source of income is extremely valuable to the farmer. Many of the intercrops during this stage consist of the fast-maturing annuals that serve as the main source of livelihood while waiting for the slow-maturing perennials to produce. Secondly, cultivation of the intercropped annuals provides an effective control of weeds, a major problem in young tree plantations. Finally, there is minimal competition both for solar energy and for soil nutrients from the small and slow-growing main crop at this stage, so the potential yield of the intercrop is almost as good as that in open areas.

The Reproductive Stage

At the reproductive stage, the perennial canopy reaches its full size, ground cover is dense, and shading between trees is at its maximum. Crops chosen for intercropping at this stage must have good tolerance to shade or, better still, should be shade-requiring crops. Most of the important annual crops discussed in Chapters 2 and 3 are not shade tolerant and are usually unproductive when used in intercropping at this stage. Even with the recent intensification of breeding programs for shade tolerance, experience has shown that it is not easy to develop high-yielding varieties of the fast-maturing annual crops that can tolerate low levels of sunshine. Thus, the growing of the annual grain crops and vegetables as intercrops at the reproductive stage is not commonly practiced.

The commonly-grown intercrops at this stage are those perennial species that are shade-tolerant and that are shorter and smaller in stature than the main crop, such as bananas, pineapples, coffee, lanzones, cacao, cinnamon, nutmeg, and black pepper.

The Stage of Senescence

During senescence, the tree is approaching the end of its life cycle. The canopy has reached its maximum size, shading is slowly decreasing, and the amount of solar energy that penetrates the canopy is increasing. The intercrops during this stage may consist of the following: continuation of the well-established perennial intercrops planted at the reproductive stage; return to the annual crops grown at the seedling stage; and replanting of young trees to replace the ageing main crop. If the perennial intercrops have a long life cycle, perennial intercrops are usually used. These intercrops usually give high returns, which may even exceed those of the main crop, so that the farmer's preference is to allow them to produce for as long as possible. In some cases, the intercrop may be maintained over two generations of the main crop, i.e., the intercrop occupies the area even as the original trees of the main crop are replaced by younger ones.

Intercropping with annual crops is used commonly during the latter part of senescence for two reasons. First, light interception by the old tall canopy of the main crop is sufficiently reduced and light penetration is high enough to support a satisfactory yield from annual intercrops. Secondly, the temporary land occupancy by the fast-maturing annual makes it an ideal intercrop in anticipation of the replacement of the ageing main perennial crop. A perennial intercrop could, at this time, interfere with the systematic replacement of the ageing main crop, especially so if a new crop or a new plant spacing is to be used.

Replanting to replace the ageing main crop is the traditional procedure for maintaining the productivity of a coconut farm. Young coconut seedlings are planted between the senescent trees such that the new trees are starting to bear when the old ones are removed. This avoids the prolonged period in which the main crop is unproductive. Another advantage is the continuity of ground cover, which reduces the potential for soil deterioration and allows for the continuation of the shade-requiring perennial intercrops.

CHAPTER 5: MULTIPLE CROPPING ON HILLY LAND

Hilly land describes rugged and undulating terrain in which the topography is dominated by slopes exceeding 15%. Its importance in the agriculture of Asia is shown by several features. First, its large area (Table 5.1), if made productive, could support a large population and absorb the excess labour from the crowded lowland. Secondly, a significant number of families are illegally farming hilly land and are frowned upon by society for their alleged irresponsible and wanton destruction of natural resources. Thirdly, there is a significantly lower standard of living among the hilly-land farmers relative to their flatland counterparts. Lastly, hilly lands have the potential to destroy the productivity of the flatlands if the former are improperly managed.

Soil conservation, particularly the prevention of soil erosion, is a major consideration in hilly-land agriculture. Water moves down the steep slopes through the soil surface carrying along with it the loose soil particles. This soil movement, termed soil erosion, increases on steeper slopes, with the frequency of cultivation, and with rainfall intensity. It decreases with larger size of soil particles and with more vegetative ground cover. Because soil productivity quickly deteriorates as the rate of soil erosion increases, the choice of cropping patterns and the corresponding cultural practices in hilly lands

Table 5.1. Uncultivated land areas in Asia

Country	Uncultivated land[1]	
	Area (1000 ha)	Percentage of total (%)
Bangladesh	3666	27
Burma	55,527	84
India	114,919	39
Indonesia	151,889	84
Kampuchea	14,026	79
Malaysia	26,348	80
Philippines	20,747	70
Sri Lanka	3904	60
Thailand	33,219	65
Vietnam	22,166	68

[1] Includes the forest, woodlands, and other agriculturally unproductive areas. Most of these areas are hilly lands.

Source: FAO (1979).

must ensure that soil erosion is minimized.

Multiple cropping is an ideal tool for reducing soil erosion without sacrificing the intensity with which land can be used for growing economic crops. With adequate ground cover, rainwater does not hit the soil directly and, thus, its potential for eroding the soil is greatly reduced. Two commonly used practices in multiple cropping guarantee a continuous and effective ground cover. First, by intercropping or relay cropping, adequate vegetative ground cover can be provided during most of the year. Secondly, by using crop residues as mulch for succeeding crops, effective ground cover is provided during their early growth when the soil would otherwise be bare of vegetative cover and most vulnerable to erosion. This topic is discussed further under Annual Crops in this chapter.

The Traditional Pattern

Shifting cultivation is the oldest production technique on hilly land. The farm family moves into a virgin or mature forest, fells the trees and other forms of vegetation in the area, allows them to dry, and then sets fire to them. They plant in the cleared patch of land, getting a good yield in the first year, a reduced yield in the second year, and possibly none or very little in the third year. Then they move on, seeking new areas, and start the cutting-burning-planting process all over again. Meanwhile, the abandoned areas lie fallow during which either the lost fertility is replenished or the already poor soil deteriorates further, resulting in a barren and worthless wasteland (Lapitan 1977).

The rehabilitation, or further deterioration, of a cleared patch of land, abandoned by the shifting cultivator, depends largely on the length of time the area is left fallow. Over 25 years or more, the decline in soil productivity may be negligible (Plucknett 1977). With increasing population and the decline in areas available for shifting cultivation, however, the fallow period becomes shorter and the frequency of cropping increases. As the fallow period is shortened, soil fertility deteriorates, weeds build up that are fire-resistant or that require low fertility, more desirable bush and tree species fail to grow, and productivity level falls (Plucknett 1977).

When population density is low and land resources are unlimited, the traditional practice of shifting cultivation has many advantages. First, weeds, a major problem in dry-land culture, are controlled effectively with the use of a long fallow period. Second, soil fertility is replenished biologically during the fallow period with very little effort from, and expense to, the farmers. Third, with the cultivation of isolated patches of land in the middle of a stable and diverse natural vegetation, insect pests and diseases hardly reach population levels that can significantly reduce productivity. Fourth, with biological control of pests and replenishment of soil fertility, there is little need for any exogenous input to the production system. The farmer is independent of inaccessible markets. And fifth, when the farmer moves to a new location, trees in the new area provide materials for the construction and maintenance of a house.

The New Cropping Patterns

When the fallow period becomes too short for the effective biological replenishment of the depleted nutrients in the soil, shifting cultivation becomes a very destructive practice. Thus, as population pressure increases and land resources become limited, cropping patterns must be devised that allow for continuous crop production without the accompanying soil deterioration. Cropping patterns capable of achieving what Plucknett (1977) aptly calls the "twin goals of productivity and conservation", can be classified into three categories: those involving perennial crops; those involving both perennial and annual crops; and those involving purely annual crops.

Perennial Crops

Perennial crops are good conservers of soil on hilly land because of their long life cycle, minimum cultivation requirement, and lush canopy that provides ground cover. The natural forest of most undisturbed areas of the tropics are, in fact, primarily composed of perennial species. By growing perennial crops, therefore, continuous production is achieved while the stability and conservation properties of the natural forest are retained; two good examples are fruit-tree farming and industrial forest plantation.

Fruit-Tree Farming. Fruit trees are good soil conservers once they are fully established and have adequately covered the soil with their large and dense canopies. However, while the seedlings are still young and small, ground cover is usually inadequate and, thus, even fruit trees must be managed carefully to avoid excessive erosion. This can be done in two ways. First, soil tillage must be minimized. Secondly, cover crops, preferably leguminous vines, should be established immediately after planting of the fruit trees so that the bare soil is quickly covered with vegetation. Another alternative is to plant annual crops between the developing fruit-tree seedlings. Aside from the benefits of conservation, the fast-maturing annuals provide badly needed income while the main fruit crop is still unproductive.

After the fruit trees are fully established, other profitable perennial crops requiring some shade, such as lanzones, cacao, and coffee, may be planted between the trees (Carlos 1977). These crops promote ecological balance with respect to pests, minimize soil erosion, and strengthen water retention in the soil.

Perennial fruit trees have other desirable features that make them suitable for hilly lands (Carlos 1977), namely: many fruit trees are ecologically adapted to hilly lands; income is regular once the trees start bearing fruit; capital and labour requirements are usually within the farmer's resources; their products can be used directly as food; and the economic benefits from perennial fruit trees ensure proper management and serve as a good insurance against the cut-and-burn practice.

Industrial Forest Plantation. Industrial forest plantation is defined as a plantation of economic trees on open lands for the production of timber, pulpwood, poles, fuel, and other forest products used for satisfying the raw material needs of wood-based industries (Valera 1974). Tiongson (1974) suggested four important features of an industrial forest plantation: first, the forest is man-made; secondly, its growth rate is fast; thirdly, wood production is very efficient; and fourthly, there is regularity in quality, size , and distribution of the stand. Industrial forest plantations are similar to fruit-tree farms in that perennial trees provide good soil cover and do not need constant cultivation. On the other hand, the economic yield from industrial forest plantation comes primarily from the vegetative part (i.e., trunks and leaves) instead of from fruits.

A good example of an industrial forest plantation is that developed by the Paper Industries Corporation of the Philippines (PICOP), which is designed to maintain a continuous supply of raw materials (pulpwood) for its pulp-and-paper mill (PCARR 1979). Farmers in the vicinity of the PICOP mill are encouraged to plant the fast-growing tree, *Albizzia falcataria* through incentives provided by PICOP -- guaranteed market, credit and technical assistance, and *Albizzia* seedlings. A typical contract-farmer divides his plantation into eight lots, with one lot scheduled for planting each year. *Albizzia falcataria* is ready for harvest after eight years so that, after the first harvest, one lot is harvested every year. Succeeding crops grow from the coppice that sprouts from the stumps of the harvested trees. The cost per hectare for establishing such a plantation is estimated at $231, 75% of which can easily be borrowed by the farmers from local banks. The average farmer harvests 300 m^3 of pulpwood per hectare valued at $2400 in a market guaranteed by PICOP (PCARR 1979).

Industrial forest plantations can become very important in hilly land development for several reasons:

a) With the attractive economic benefits, farmers are committed to protect and take care of the trees from establishment to maturity.
b) Soil conservation is assured because denuded areas are converted back to forest and, in the process, settlers are provided with gainful employment that allows them to support their households.
c) The ever-expanding industrial requirement for wood can not be satisfied solely from natural forests because the latter are being liquidated quickly and second-growth forests are not very productive.
d) There is a fast-increasing pool of production technologies for more profitable and versatile industrial forest plantations. One such technology is the identification of fast-growing tree species such as *Leucaena leucocephala*, *Albizzia falcataria*, and *Eucalyptus deglupta*.

Perennial + Annual Intercropping

The differences in stature and cultural requirements between perennial and annual crops minimize competition and allow for their complementary growth as intercrops. The annuals grow fast, mature quickly, and are harvested shortly after planting, but they require constant cultivation that could cause soil erosion on steep slopes. In contrast, the perennial crops grow slowly and require a long period from planting to harvest, but, once planted, they require little maintenance or soil cultivation and, hence, soil erosion is minimized. Thus, the annual + perennial intercropping provides both the good soil conservation of the perennials and the short-growing period of the annuals.

Among the numerous annuals that can be grown with perennial trees, the annual grain crops are the most popular in the hilly lands. They have two features especially desirable in hilly areas where farm-to-market roads are usually poor and transport of goods to market, and back, is difficult. First, they are used primarily as staple food and can be used directly by the farm family or easily sold in the local markets. Secondly, they are easy to store and can be kept for future use.

The second popular alternative is the root crops such as sweet potatoes, cassava, and taro. These crops are not only efficient producers of energy but also are commonly used as staple food when cereal grains are not available. Although root crops are not as easily stored as grain cereals, the problem is partially solved by the usual practice of harvesting the crop on an "as-you-need-it" basis (Librero 1977a). Many of the root crops have the ability to stay dormant and remain fresh for long periods if the roots are left underground unharvested.

The perennials that are commonly used for intercropping with annual crops are coconuts and perennial legumes. Coconut intercropping was described in Chapter 4, so only a brief description of intercropping with the perennial legume, *Leucaena leucocephala*, is given here.

A cropping pattern that has shown good promise for hilly land is an intercrop of *Leucaena* and an annual grain crop. The technique is to grow *Leucaena* in hedge rows and corn (or other cash crops) between the rows of *Leucaena*. The versatility of this system is illustrated by the following findings (Mendoza et al. 1975). A high production of dry matter (9.54 to 24.07 t/ha/yr) and a high value of crude protein (1.54 to 5.28 t/ha/yr) can be obtained. *Leucaena* leaves may be used as mulch between the rows and, on decomposition, supply nutrients to the cash crops. During the dry season when sun-drying is easy, *Leucaena* leaves can be dried and mixed with swine and poultry ration. Net return per hectare for feed production using *Leucaena* leaves is estimated at $611/yr. The permanent hedge rows of *Leucaena*, and the ground cover it provides, reduce soil erosion in sloping areas. The annual crops usually grown between the *Leucaena* hedge rows, such as corn, sorghum, and mung beans, are fast-maturing and can be used directly as food or sold in the local market for much-needed cash.

The *Leucaena* + corn intercrop was used by Mercado (1980) to improve the yield of corn in the calcareous hilly lands of Central Philippines. The existing average yield of corn, grown in pure stands without inorganic fertilizers, was 0.3 t/ha/crop. By growing three or four rows of corn between the double hedge rows (2 to 3 m/row) of *Leucaena*, corn yields increased to 1.1 t/ha/crop after three years, provided that all the *Leucaena* herbage (cut every 60 days) was incorporated into the soil.

Annual Crops

With increasing pressure of population and the continuous fragmentation of cultivated areas into smaller farms, the cultivation of annual crops in hilly lands is expected to increase in spite of their poor soil conservation properties. The reasons for this are as follows:

a) Productivity (in terms of calories per unit area of land per unit time) for the annual cereals and root crops, which provide the most important staple foods for Asian farmers, is higher than for perennial crops. Rice or sweet potatoes, for example, produce more than twice as many calories as mangoes or coconuts (Table 5.2).

b) The potential of annual crops to absorb labour is much higher than for perennial crops (see Table 5.2).

c) With the short life cycle of the annuals, stability of production and flexibility in what can be produced is greatly enhanced. For example, after a disaster, a new crop can be sown and harvested within a short period. Also, growing new crops to adjust to changing requirements of family or market is easily implemented.

Although cropping patterns involving only annuals should be discouraged in hilly areas, it has been shown that, in gently sloping areas, multiple cropping of annual crops alone coupled with the proper choice of crop and soil management can achieve the twin objectives of productivity and soil conservation. Some management practices in cropping patterns involving annual crops are known to reduce soil erosion.

Intercropping and Relay Cropping. By intercropping and relay cropping, the ground is provided with continuous vegetative cover, which most effectively reduces soil erosion in the humid tropics. Intercropping increases the rate at which the crop canopy covers the newly planted soil, and relay cropping eliminates the period between crops when the soil would otherwise be bare. By intercropping cassava with corn, for example, 50% ground cover is attained in 50 days compared to 63 days for cassava in monoculture (Lal 1980). The intercropped cassava had significantly less soil and water loss compared to that in monoculture (Table 5.3).

Table 5.2. Productivity and labour requirements of some annual and perennial crops

Crop	Yield[1] (t/ha/yr)	Energy equivalent (1000 calories)	Labour requirement[2] (man-days/yr)
Annual crops			
Rice	5.6	20,608	232
Corn	4.4	8272	139
Sweet potatoes	20.0	27,200	180
Tomatoes	20.0	3800	288
Perennial crops			
Papayas	15.0	7200	229
Coconuts	3.0	9000	38
Mangoes	10.0	8300	86

[1] For annuals, computation is based on a sequence of two crops per year.

[2] For perennial crops, it represents the requirement for maintaining productive trees.

Source: Derived from Tables 2.12, 3.5, 4.1, and 4.3.

Table 5.3. Comparison of soil and water loss on different slopes in cassava monoculture and in cassava + corn intercrop

Slope (%)	Soil loss (t/ha)		Runoff (% of rainfall)	
	Cassava	Cassava + corn	Cassava	Cassava + corn
1	5	3	18	14
5	87	50	43	33
10	125	86	20	18
15	221	137	30	19
Mean	109	69	28	21

Source: Aina et al. (1977).

Residue Mulching. Mulching with crop residue prevents the direct impact of raindrops on soil aggregates, increases soil porosity and infiltration rate, and decreases bulk density, resistance, and structural instability (Lal 1980). From newly cleared land in the Ibadan soil series, runoff and soil loss decreased exponentially with an increase in mulch rate (Table 5.4).

Zero Tillage. Zero tillage has both direct and indirect influences on soil erosion. It prevents the formation of a thin crust or impermeable layer which usually accompanies plowing. Thus, water infiltration in uncultivated soil is expected to be higher than in cultivated soil. Indirectly, zero tillage reduces the time required for establishing a crop and, thus, the vegetative cover that is so important in reducing soil erosion. Greenland (1975) showed that zero tillage significantly reduced the amount of soil and water loss in corn crops grown at different slopes (Table 5.5).

Contour Farming. In contour farming, the tillage operations leave miniature furrows along the contour that minimize the flow of rainwater

Table 5.4. Effect of mulch rate on soil and water loss at 10% slope

Mulch rate (t/ha)	Runoff (% of rainfall)	Soil loss (t/ha)
0	17.4	9.6
2	10.0	2.3
4	3.5	0.5
6	1.2	0.1
12	0.0	0.0

Source: Lal (1980).

Table 5.5. Effect of zero tillage on soil and water loss in a corn crop

Slope (%)	Soil loss (t/ha)		Runoff (% of rainfall)	
	Zero tillage	Plowed	Zero tillage	Plowed
1	0.03	1.2	1.5	7.1
10	0.08	4.4	2.6	6.5
15	0.14	23.6	2.7	11.5

Source: Greenland (1975).

down the slope. Water movement is further restricted by the crop rows acting as barriers. However, contour farming is effective only in gently sloping areas where water movement down the slope is slow. Where water movement down the slope is too voluminous and too fast, the contour furrows may break and soil losses may even be increased (Lal 1980).

Terracing. In terracing, a continuous slope is modified into a series of level plateaus resembling a stairway. Each level plateau, termed a terrace, is made by moving soil from the upper to the lower end of the slope.

Aside from facilitating cultural management, terracing is very effective in controlling erosion and can be used in areas with up to 50% slope. The main constraint, however, is the high requirement for labour. For example, it takes 500 man-days per hectare to construct bench terraces four metres wide on a 30% slope (Somyos Kejkar 1978). High labour costs can be reduced by other alternatives such as discontinuous terracing, in which terraces are constructed at intervals along the slopes leaving some natural slopes for possible treatment at a later time, and contour bunds, in which bunds are constructed at regular intervals along the contours of the slopes to break water movement.

With the reduction of soil movement down the slope through proper crop and soil management, multiple cropping with annual crops can be implemented with a much-reduced danger of soil deterioration.

Determinants of Cropping Patterns on Hilly Land

Because productivity is as important in hilly lands as in the flatlands, most of the determinants of cropping pattern discussed in Chapters 2 to 4 apply also to hilly lands. However, with the great importance of soil conservation attached to cropping hilly land, three primary determinants are discussed here which focus on the objective of soil conservation, namely: slope, rainfall, and soil properties.

Slope

In the humid tropics of Asia, the major cause of soil erosion on hilly land is the movement of surface water down the slope. The faster the water moves, the more soil particles it carries and the more serious is the soil erosion. The rate of water movement down the slope is related to the grade and length of the slope. Steeper and longer slopes cause faster movement and are, therefore, more prone to excessive soil erosion.

The prime way to reduce soil erosion on hilly land is to decrease the rate at which water moves down the slope. This can be done (as previously described) by providing physical barriers across the slope, either by movement of earth, by mulching, or by growing vegetation, so that water movement is intermittently arrested or diverted and, consequently, is slowed down.

Because soil movement, like land leveling, is expensive, vegetative barriers have been more extensively used, particularly in remote areas where construction and maintenance of structures are difficult. The effectiveness of vegetation cover depends on plant size, with the larger plants more effective than smaller ones; length of life cycle, with the slow-maturing plants more effective; and density of ground cover, with the dense stands more effective than sparse stands.

In developing a policy for land use, the importance of slope is generally recognized, as illustrated by the land capability classification both for Japan and for the Philippines. In Japan, gently sloping fields (5% or less) are to be used for production of vegetables, middle slopes (8 to 15%) for fruit production, steep slopes (6 to 30%) for uncultivated grasslands, and beyond 30% slope for forest trees (Yahata 1977). In the Philippines, slope is also the primary determining factor for the recommended type of vegetation to be grown in the different land capability classes (Table 5.6). Canopy size, length of life cycle, and density of the recommended ground cover increases as the slope becomes steeper. On very steep slopes, dense and uncultivated natural forest stands are recommended.

Slowing the water movement down hilly slopes results in two desirable features. First, erosion is minimized, and secondly, water is retained in the catchment and is available to the plants for a longer period. Thus vegetation becomes denser and, with time, the environment improves.

Rainfall

Rain not only dislodges soil particles and compacts the soil, but also is the primary source of water that moves down the slope. Thus, the potential for soil erosion, and consequently the requirement for soil conservation, increases with rainfall intensity.

The harmful effect of rain falling on bare soil is greatly reduced by providing good ground cover all year round. A vegetative cover breaks the fall of the raindrops resulting in a reduction of their speed and size before they reach the soil. Also, falling rain that hits the plant canopy does not immediately drop to the soil below, but is held by the leaf surface for some time thus reducing the rate at which the water hits the soil surface.

The beneficial effects of vegetation on water movement down the

Table 5.6. Description, area, and recommended crop or management practices for the different land capability classes in the Philippines

Capability class	Description	Area (%)	Recommended crop or management practice
A	Very good land, can be cultivated safely	5.30	Simple management
B	Good land, can be cultivated safely	9.61	Simple conservation
C	Moderately good land, can be cultivated with extra caution	4.30	Intensive conservation
D	Fairly good land, can be cultivated with extra caution	8.63	Complex conservation; pasture or forest
L	Level, too stony, and very wet	0.01	Pasture or forest crops
M	Steep land, can not be cultivated	49.65	Pasture or forest crops
N	Very steep land and eroded, can not be cultivated	13.93	Pasture or forest crops
X	Level, can not be economically drained	2.05	Fishpond, recreation
Y	Very hilly and mountainous	6.52	Recreation and wildlife

Source: Concepcion (1977).

slope were discussed under Slope. The more serious an erosion problem becomes, the more advisable it is to use large perennial trees, which can provide good ground cover all year round and can thrive adequately without regular cultivation. Thus, for hilly lands with high rainfall intensity, large perennial trees are recommended and the cultivation of annual crops should be avoided.

Soil Properties

The rate of soil movement down the slope depends upon the soil characteristics. First, soils with a higher water-holding capacity allow for faster rates of infiltration, thereby reducing the amount of runoff and soil erosion. Secondly, soil aggregates, in which the particles are more strongly bound to each other, are less affected by the movement of surface water. Organic matter plays an important role as a binding agent for soil aggregates, and for this reason areas with permanent vegetative cover, such as the natural forests and grasslands, are expected to have an improving, rather than deteriorating, soil condition. Aside from protecting the soil from raindrops and rapid runoff, the vegetation constantly adds organic matter to the soil resulting in continuous improvement in its physical and chemical properties. Unfortunately, the destruction of vegetative cover quickly triggers a return to a deteriorating cycle. Thus, bare hilly areas should be restored to vegetation as quickly as possible.

In terms of cropping patterns, this means that: first, the more deteriorated is the soil, the more urgent is the need to plant perennial crops; secondly, no annual crops should be grown on hilly areas that are in an advanced stage of deterioration; and thirdly, because of the quickness of soil deterioration on steep slopes, these areas should never be without a vegetative cover.

PART II

RESEARCH METHODOLOGY

CHAPTER 6: INTRODUCTION TO MULTIPLE-CROPPING RESEARCH

Research in Multiple Cropping

Research in multiple cropping is concerned with the testing and evaluation of crop-production strategies that are packaged at the cropping-pattern level to maximize productivity, not only of a single crop component, but also of the cropping pattern as a whole (see Chapter 1). The need to evaluate production packages at the cropping-pattern level instead of at the more traditional crop level arises from the interaction among crop components in a cropping pattern (e.g., performance of a given crop is dependent upon its particular position in the cropping pattern). If such interaction is large, the production package that maximizes productivity of a single crop is not likely to be the same as that which maximizes productivity of the whole cropping pattern. Interactions among crop components are caused by several effects.

Competition Effect. This is most pronounced in intercropping or relay cropping, when two or more species occupy the same piece of land simultaneously. The intercropped species compete not only for sunshine and carbon dioxide in the air, but also for water and nutrients in the soil. Thus, species that absorb soil nutrients more efficiently, or that intercept more solar energy in the canopy, reduce the resources available to, and the yields of, their competition. This is illustrated by the corn + mung-bean intercropping in which yield reduction in mung beans is much larger than that in corn (see Table 3.9) due to the corn's taller canopy that intercepts more solar energy.

Complementary Effect. This is the opposite of competition effect and is also most pronounced in intercropping. Three types of complementary mechanism have been reported. First, some crops emit substances that protect or nourish others. For example, in a cabbage + tomato intercropping, tomatoes were reported to emit a substance that acts as an insecticide against a cabbage pest, *Plutella xylostella* (L.) (Buranday and Raros 1975). Secondly, one crop may suppress the harmful effects of some pests thus benefiting the other crop. This is illustrated by the mung-bean + corn intercropping in which, under the condition of no weed control, corn yields were higher than in the corresponding pure stand (see Table 3.9). Apparently, the mung beans reduced weed growth significantly, thus resulting in a higher productivity of the corn intercrop. Thirdly, some species may even benefit from reduced levels of certain resources under intercropping. This is the case with coconut + taro intercropping in which productivity of the shade-requiring taro is enhanced by reduced solar radiation under the coconut canopy (Carandang 1979).

Residual Effect. This is the effect of the previous crop in a sequential cropping pattern on the productivity of the current crop. There are two major types of residual effect. First, some crops exude chemical compounds into the soil which affect the succeeding crop. This is illustrated by the poor growth and low yield of mung beans grown immediately after mung beans (Sikurajapathy 1974). Secondly, the application of some chemicals, as fertilizer or pesticide, to the previous crop can benefit the succeeding crop by making extra nutrients available to it. This could be due to an overdose of fertilizer in the previous crop, or to the poor growth of the previous crop from lack of pesticide application.

Planting Date Effect. In a cropping pattern, a shift in the planting date of one crop greatly affects the planting dates of the others. Because planting date is a very important determinant of crop yield and can spell the different between the crop's success or failure, much of the interaction among crops in a cropping pattern is due to the interdependence of their planting schedules.

Thus, a change in the orientation of research is required from the traditional monocrop research, in which only one crop is considered at a time, to a multiple-cropping approach in which emphasis is on a simultaneous investigation of the interaction between all crops in a cropping pattern. Multiple-cropping research has several features that are distinct from monocrop research.

Large Number of Factors to be Tested

With several crops to be examined simultaneously, the total number of factors to be tested is usually equal to the sum of all factors in each individual crop. Thus, the total number of factors to be tested in a multiple-cropping experiment is generally large.

Because there is interaction among crops, it is necessary to examine the interrelationships or interactions among factors not only within individual crops but also between component crops. Hence, the size of multiple-cropping experiments is usually too large to be handled efficiently with the traditional monocrop research procedures. Consequently, multiple-cropping experiments are usually conducted in two phases. In the first phase, a single experiment is conducted with a large number of factors tested simultaneously, with each factor having only a few, usually two, levels tested. The purpose of this experiment is to measure the magnitude of interactions among the many factors tested and to identify those factors that interact negligibly with others. In the second phase, each of the factors with negligible or no interaction are tested in a single-factor experiment separately from the others, whereas those with large interactions have to be evaluated in one or more multi-factor experiments. With the smaller number of factors to be tested in each experiment in the second phase, more levels can be tested for each.

Non-Uniform Plot Techniques for Different Crops

Plot size, number of replications, border rows, and management practices are some of the features of field experiments that are specified by a field plot technique. Unfortunately, even among annual crops, the plot techniques suited to one crop are not usually suited to others for several reasons.

Plot Size and Number of Replications. Different crops generally have different degrees of variability, for example, that in lowland rice is less than that in upland rice, and, among upland crops, sweet potatoes have a much higher degree of variability than corn. The determination of plot size and of number of replications is largely influenced by the degree of variability involved, with larger plot sizes and more replications required under higher levels of variability. Moreover, because the choice of plot size and shape is affected by the distance of planting (plant spacings) used, plot sizes and shapes commonly used in field experiments vary greatly from one crop to another. For example, in the Philippines, the minimum net plot sizes (i.e., harvest area with borders excluded) for varietal trials are 5.0 m^2 for lowland rice, 7.5 m^2 for corn, sorghum, and soybeans, and 10.0 m^2 for sweet potatoes.

Border Rows. Border rows refer to plants at the periphery of the plot that serve as buffers for possible border effects due to treatments applied to adjacent plots or areas. These border rows, although constituting a part of the plot, are generally not used for yield determination or for any other measurements. Because crops differ in their ability to influence adjacent plants as well as in their row spacings, the sizes of border rows required vary for different crops. For example, in varietal trials in the Philippines, two border rows are required for rice, one for soybeans and sorghum, and none for corn.

Management Practices. Because the recommended management practice for each crop is designed to maximize its productivity, very different management practices might be expected for the widely divergent crop species usually included in a cropping pattern. For example, small-statured species such as peanuts are planted with a closer plant spacing (50 x 10 cm) than larger species such as corn (with plant spacing of 75 x 25 cm). The amount, and method, of fertilizer application also differs for lowland rice grown in submerged soil as compared to upland crops.

The plot technique used in a multiple-cropping experiment must take into account the requirements of each, and all, of the crop components in the cropping pattern. Because it is generally advisable to use a uniform plot size in an experiment, that in a multiple-cropping trial involving different crop species should follow the plot size for the crop with the largest requirement. If, for example, the cropping pattern to be tested includes rice, corn, and sweet potatoes, the plot size used should be that required by sweet potatoes, which is the largest of the three.

Row spacings of different crops being evaluated in the same growing season should be a multiple of one another for convenience in furrowing and to avoid error in setting different furrow distancing. For example, in a trial involving corn and peanuts, in which the usual row spacings are 75 cm for corn and 50 cm for peanuts, one of the following alternatives could be chosen: to use row spacing of 50 cm for both crops; to use row spacing of 75 cm for both crops; or to use row spacing of 40 cm for peanuts and 80 cm for corn.

Because conducting an experiment is greatly complicated by the wide diversity of the management practices required by individual crops, it is advisable, whenever possible, to select a practice acceptable to all crops in the experiment. For example, in chemical weed control, although Herbadox is a good herbicide for corn, it can not be used for mung beans. Atrazine, however, can be applied to both corn and mung beans although its effectiveness on corn is not as good as that of Herbadox. Thus, if corn and mung beans are grown together in the same experiment, it is simpler to use Atrazine on both crops.

Alternative Measures of Productivity

In monocrop research, the weight of the most important economic yield is generally used as the index of productivity. This index is quite adequate for experiments involving a single crop because the weight of its one product is also indicative of other indices such as those for economic or nutritional values. However, in multiple-cropping research, several crops are usually involved and their products are likely to be heterogeneous, so the use of total weight of all products cannot be used as the sole index of productivity. Heterogeneity among products of different crops makes the weight index (total weight of all products) less meaningful and not indicative of other important indices, such as those representing economic or nutritional values.

There are at least two alternatives for dealing with this problem. The first is to use the yield of each component crop separately, such that the best cropping pattern would be the one that excels in all crops. It is, however, not unlikely that a cropping pattern with the best yield in one crop component has lower yields in other crop components, and the best cropping pattern is, thus, not easily identified. Therefore, some arbitrary decisions still have to be made in order to select appropriate criteria in the evaluation process.

The second alternative is to aggregate the yields from the different crop components into a single productivity index by assigning some arbitrary weights to each and every crop based on the perceived relative values of their products. The productivity index, $\underline{P}$, of a cropping pattern is then computed as:

$$P = \sum_{i=1}^{n} (a_i X_i - b_i) \qquad [6.1]$$

where $\underline{a_i}$ is arbitrary weight for the $\underline{i}$th crop, $\underline{X_i}$ is yield of the $\underline{i}$th crop, $\underline{b_i}$ is arbitrary constant for the $\underline{i}$th crop, and $\underline{n}$ is total number of crops in the cropping pattern.

The advantages of a single productivity index are many. Productivities of the different cropping patterns tested are easily ranked, data analysis is simplified, and the index itself represents the single most important property of the production technology tested. However, because such a productivity index is specified by a set of weights and constants ($\underline{a}$ and $\underline{b}$) prescribed for each and all crops and, because the number of possible sets of $\underline{a}$ and $\underline{b}$ is infinite, the number of possible indices is also infinite. Two of the most commonly used bases for selection are market price, expressed as a monetary index, and calorie equivalent in which the index is expressed as an energy unit (Table 6.1).

Table 6.1. An illustration of the computation of a monetary index and a calorie index for a rice - corn - mung bean cropping pattern

Item	Unit	Rice	Corn	Mung beans	Index value
Yield (X)	t/ha	3.0	2.5	1.0	-
Value of product					
Price (a)	\$/t	160	133	667	-
Calories (a')	10^4cal/t	368	188	356	-
Cost of production					
Price (b)	\$/ha	361	228	224	-
Calories (b')[1]	10^4cal/ha	165	133	165	-
Monetary index					
a X - b	\$/ha	119	104	443	666
Calorie index					
a'X - b'	10^4cal/ha	939	337	191	1467

[1] Assumes all operations to be done by man and animal. Calorie values for man and animal power, fertilizer, and pesticides were taken from Librero (1977b).

The primary appeal of the monetary index is its practical usefulness and simplicity of meaning. A monetary value on the farm output is easily understood and is meaningful to both researcher and farmer. Its major weakness, however, is that, because prices of agricultural products vary widely over time and location, the monetary index is pertinent only to the location and time for which the computation was based. Its real value changes greatly over time and for different locations. In the Philippines, for example, the average monthly price of one kilogram of tomatoes in 1978, ranged from a low of \$0.09 in March to a high of \$0.79 in December.[3] Using the monetary index, therefore, a cropping pattern could be judged superior in one environment not because of an inherent biological advantage but simply because commodity prices at the time were very favourable, a condition that could change drastically with time and place.

The calorie equivalent, on the other hand, is based upon the inherent character of the product itself and is independent of external factors, but it is not as easily understood nor as easily appreciated by farmers as is the monetary index. A high calorific value is generally not directly related to profitability, and so is not a good selection criterion as far as the farmer is concerned.

It is, therefore, extremely important that the most suitable index be selected for each experiment. Hildebrand (1976) suggested the following criteria as the bases for the choice of a productivity index:

(a) It must be common to all products and inputs and must provide the means for comparing different cropping patterns;

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[3] Central Bank of the Philippines Annual Report, 1978.

(b) It must be relatively easy to measure;
(c) It must be capable of reflecting quality differences between the products; and
(d) It must be meaningful to the farmer in such a way that it helps him to allocate his resources between competing uses.

Also, Flinn (1978) suggested that the productivity index must also be meaningful to the researcher so that new technologies can be compared with existing ones.

No single productivity index, at present, satisfies all these requirements. For example, the monetary index satisfies all except requirements (b) and (c), whereas the calorie equivalent satisfies only items (a), (b), and (c), but not (d).

The choice of an appropriate index is not easy, and the following guidelines are suggested. First, the objective of the experiment should serve as the primary basis for selecting the productivity index. For example, if the objective is to develop a technology the primary concern of which is to give maximum profit to the farmers, then the monetary index is probably best. On the other hand, if the primary objective is to combat malnutrition, then the calorie equivalent may be more appropriate. Secondly, if the use of a single productivity index cannot satisfy all the objectives of the experiment, several indices should be used. For example, both the monetary and calorific indices could be used in the same experiment to identify production technologies that are excellent in both measures. Closely related to the research objective, the identification of an appropriate index, or indices, for a given experiment should be considered as a part of the design and planning of the experiment itself.

Measurement of Labour Requirement

Labour is an important contributor to the cost of production and, therefore, influences greatly the profitability of a technology. The labour requirement and its temporal distribution are important considerations in evaluating productivity and acceptability of a production technology. In cases where the availability of farm labour is limited, adoption of the new technology could be premised on the assumption that its labour requirement is within the farmer's reach. For monocrop experiments, because cultural operations do not vary widely among treatments and the labour requirements of the different treatments are generally not too different, actual measurements of labour requirement for individual treatments are usually not necessary. On the other hand, where several crops are involved and where each component crop involves major changes in its culture and management, the labour requirements vary considerably among the different cropping patterns, and actual measurements of man-hours used for the different operations are often required.

Relative to the usual measurement of agronomic data, the measurement of labour requirement has three distinctive features.

Replication Not Needed. Replication, which is almost always needed for the measurement of such agronomic characters as yield, is generally not needed in the measurement of labour requirement. The among-plot variation in labour requirement is generally smaller than that for most agronomic data. For example, fertilizer is usually applied to the soil surface on a non-rainy day, and the labour used for its application is hardly affected by either the slope, the soil property, or the climatic condition.

Need for Larger Plots. For some field operations, the labour requirement needs to be measured in relatively larger plots than those required for the measurement of agronomic data. This is because labour efficiency is greatly reduced by too many idle turns required by performing operations in small plots. For example, the rate at which a person can plow the land, apply insecticide, or apply fertilizer is higher the further he can move without turning. Thus measuring the labour requirement for operations in small plots can be unrealistic. On the other hand, its measurement for such operations as hand weeding or harvesting could be satisfactorily done in relatively smaller plots than those needed for, say, land preparation.

Not All Plots Need to be Measured. The labour requirement need not be measured for all operations or for all cropping patterns. Measurement should be made only if it is expected to vary considerably from one treatment to another, or when no prior information is available. Land preparation, hand weeding, and harvesting are generally considered to be operations greatly influenced by differences in the component crops and technology used. They should have their labour requirement measured for the varying treatments and cropping patterns tested. On the other hand, if the only difference is the frequency of the operation, such as the number of fertilizer applications, then labour requirement need not be measured for all treatments but only for that treatment with the minimum frequency. The labour requirement of the rest of the treatments is then estimated by direct computation. When the cropping pattern to be tested involves a relatively new technology, such as the direct-seeding of rice, prior information on the labour requirement may not be available, and its measurement is necessary. However, because the labour required for broadcasting of seeds is not expected to be greatly influenced either by other component crops (e.g., the previous crop) or the corresponding component technology (e.g., the time of planting or the management practices employed), such measurements need not be made for all treatments.

Large Interaction Between Technology and Environment

Production technologies in multiple cropping are generally perceived to be environment specific, that is, the best production technology for one environment is not necessarily the best for other environments. There are two possible reasons for this. First, multiple cropping increases the diversity of the environments under which the component crops in the cropping pattern are grown. In contrast to a monocrop pattern in which the growing period for the crop can be timed to coincide with the most favourable season of the year, in multiple cropping, the flexibility in selecting a favourable planting date for a given crop is small since several crops have to be considered simultaneously. Consequently, a component crop in a multiple-cropping technology could be exposed to the different crop seasons of the year, as in sequential cropping, or to a very variable degree of solar energy interception, as in intercropping, such that the variation in the environments could be large even within the same location. As the environmental variation increases, the chance of having a large interaction between technology and environment is also greater.

Secondly, in a given situation, the number of possible multiple-cropping patterns is much greater than that of the monocrop patterns. For example, in an area where three species of annual upland crops can be grown, there are only three possible monocrop patterns, but there are six possible double croppings, six possible triple croppings, and several possible intercroppings. With the large number of possible cropping patterns, the multiple-cropping production technology is more diverse and the interaction between technology and environment is expected to be larger than that under monocrop.

The potential for a large interaction between technology and environment increases the complexity of the experiments in multiple cropping. When the effect of such interaction is absent, or very small, the results of trials conducted in one or more environmental conditions can be applied to many others. On the other hand, when the interaction is large, research results from one environment cannot safely be applied to other environments.

Types of Experiment in Multiple Cropping

Research in multiple cropping can be classified two ways based on the research objective and the research site.

Research Objective: Technology Generation Versus Technology Verification

The task of developing new technologies more productive than those currently in use by farmers can be divided into two phases -- technology generation and technology verification.

Technology Generation. Experiments in technology generation are mainly designed to maximize biological yields or to devise management practices that can give high yields at minimum cost.

Procedures for achieving this objective are many and diverse but they share some common features. First, production techniques are usually broken into specialized components that are studied separately. For example, the problem of soil may be isolated from that of pests and from that of seed improvement. Each problem is studied separately and intensively by soil scientists, entomologists, and plant breeders, respectively. Secondly, many different speculative techniques are tried and, although many are expected to fail and do so, a few exceptionally productive ones are discovered. Thirdly, experiments usually require effective control of the environment and close supervision by senior scientists, requirements both of which are more easily met in a research station than in a farmer's field. Thus, although experiments for technology generation can be conducted either in a research station or on farmers' fields, they are more frequently conducted in a research station.

Technology Verification. Assuming that a newly developed technology will be adopted by farmers only when it is superior to their current practices, the primary objective of technology verification is to compare the performance of a newly developed technology to that of the farmer in the farmers' own environment. If the newly developed package is no better than the existing practice, its constraints -- physical, biological, or socio-economic -- must be identified and fed back to researchers for further improvement. On the other hand, if the new technology is substantially better than that of the farmer, major constraints for its adoption must be examined to develop adequate procedures for persuading farmers to adopt it.

In an experiment with the very specific objective of technology verification, the procedures for its implementation can be distinguished from that of technology generation in two important aspects. First, unlike technology generation experiments, which can be conducted either in the research station or on farmers' fields, technology verification experiments must necessarily be conducted on farmers' fields. Secondly, whereas only the physical and biological environment of a farmer's field is generally used in an on-farm technology generation experiment, technology verification experiments also use the farmer's practices and, at times, his participation in the evaluation process.

Research Site: Experiment Station Versus Farmer's Field

Traditionally, agricultural research has been confined to the research station where the following favourable conditions could be expected: regular size and shape of experimental fields; high soil productivity and uniformity; good control of environmental factors such as the availability of water; good protection against biological or mechanical damage; good facilities for processing samples and for data collection; and good accessibility to experimental fields and close supervision by the researchers conducting the trials. Such favourable conditions usually resulted in a very high level of productivity in the experimental crops that has seldom been attained on actual farms. In the Philippines, for example, average farm yields for rice and corn are estimated to be less than one-third of that shown to be possible in experiment stations (PCARR 1976). With the generally higher levels of productivity obtained in experiment stations, it is probable that the best production technologies developed at research stations may not in fact be the best for the less productive conditions on actual farms. Thus, in recent years, an increasing number of trials, especially those concerned with the evaluation of cropping patterns, have been conducted in farmers' fields. By conducting on-farm trials, a production technology is exposed to a much wider range of growing conditions than that usually available at research stations. Also, results of on-farm trials are felt to be more realistic and more attuned to the requirements and limitations of the farmers.

As a research site, farmers' fields are characterized by several features that differ distinctly from those of the research stations and that may necessitate some modifications to traditional methods of research.

Lack of Experimental Facilities. The success of an experiment depends primarily upon how well the researcher maintains uniformity in all aspects of the experiment except that prescribed by the treatments. Rat fence, a facility available in many experiment stations, is not available in farmers' fields. Independent sources of irrigation water, which could save an experiment in cases where abnormal water shortage occurs, are lacking in farmers' fields. Appropriate equipment needed to ensure a reliable determination of yield data from small plots, such as threshers and dryers, are not always available on the farms.

Variation Among Fields Within a Farm. Experimental fields in a research station are generally uniform both in size and topography. For example, the experimental fields at IRRI are divided into blocks of relatively uniform size and shape of 25 x 100 m each. Each block is uniformly graded such that very little, if any, difference in slope is left. Such uniformity in size, shape, and topography, which makes easier the planning and laying out of experimental plots, is not found in farmers' fields. The usually variable sizes and shapes of farmers' fields (or paddies) can pose an unusual restriction on the size of the experiment, on the layout of experimental plots, and on the number of treatments that can be tested. The differences in topography, landscape, or slope among fields on the same farm require that the specific fields to be used for experimentation should be selected very carefully.

Variation Among Farms. Variation in soil characteristics, water availability, management practices, and productivity among farms in a target area can be substantial. Thus, the suitability of a new production technology must be evaluated in a sufficiently large number of farms so that the anticipated range of variability among farms within the area can be adequately covered. In conducting experiments in farmers' fields, a proper balance between the number of farms and the number of replications within a farm must be maintained.

Farmer's Participation and Practices as a Farm Environment. When an experiment is conducted in farmers' fields, the following features, in addition to the natural physical and biological environment, are available for use in the experiment: First, the farmer's participation in the conduct of the experiment; and secondly, the availability of the farmer's own cropping pattern, management practices, and production levels for comparison with that of the new technology. The choice of whether to use either or both of these features will greatly influence the experimental methodology used. On-farm experiments for technology generation are almost always managed by researchers in much the same way as research station experiments. Only the biological and physical environments of the farms are actually used to represent the different test environments. On the other hand, the evaluation process in a technology verification experiment may include the participation of the farmer in the decision-making and in the actual operation of the trial to determine his managerial capability and his willingness to perform the specific management practices required by the new technology.

Two common consequences of having farmers' participation as a part of the experiment are a reduction in the accuracy with which certain treatment levels are implemented as prescribed in the experimental plan; and an increase in the frequency of experimental failure. Thus, the participation of farmers in on-farm trials should be included only when absolutely essential, such as when the new technology involves some operations that are new to the farmer so that its operational feasibility needs to be evaluated.

If the experiment is to test only amounts or frequencies of applications such as fertilizers or insecticide, the following aspects of the new technology can be examined by the researcher himself without the need for farmers' participation:

(a) Its feasibility as affected by certain physical and biological environments in the farm; for example, whether the required timeliness of the split application of fertilizer is possible under actual farm conditions where water availability is not under full control of the farmer;
(b) Its contribution to the increase in productivity; and
(c) Its benefit-cost ratio (i.e., whether it pays for the farmer to adopt the new technology).

On the other hand, if the experiment is to test a cropping pattern where one of the component crops has not been grown by the farmers in the target area, or when some of the operations involved are relatively complex, then farmers' participation should be considered.

Supervision of Experiments. Experiments in farmers' fields are generally conducted on several farms, some distance apart not only from each other but from the main research station, resulting in poorer accessibility and lower frequency of visits by researchers relative to those conducted in research stations. This could reduce the degree of experimental precision and limit the use of complex experimental procedures possible only in research station trials.

The added emphasis given to experiments in farmers' fields does not, however, eliminate the need to conduct experiments at research stations. Research station trials, where many new and speculative techniques are initially screened, are still needed to provide the new ideas and the potentially productive technologies that are the building blocks of the new technologies that can be evaluated further in farmers' fields. Experiments in multiple-cropping research are, therefore, conducted both in research stations and in farmers' fields.

CHAPTER 7: EXPERIMENTS FOR TECHNOLOGY GENERATION

Agricultural research has traditionally focused on the development of new technologies to maximize yields at minimum cost. Experiments are usually conducted in research stations, where environmental control is good and close supervision by senior scientists is facilitated, with a narrow focus on a particular component of the technology for a single crop, and for the evaluation of many speculative techniques from which only a few are expected to succeed. Research methods for conducting such trials have been well-developed and well-documented, and are not discussed in this book. This chapter concentrates instead on new methodologies developed specifically for multiple-cropping research and on traditional methods that have been modified to cope with the unique features of multiple-cropping research.

Technology Generation Experiments in Research Stations

Although technology generation experiments can be done either in farmers' fields or in research stations (see Chapter 6), a greater portion continues to be conducted in research stations where uniformity among experimental plots is greater, research facilities are better, and the large and complex experiments usually required in multiple-cropping research can be closely supervised by the scientists themselves.

Many well-established procedures exist for conducting field experiments in research stations, but most of them have been developed for monocrop experiments. In contrast, multiple-cropping experiments are usually larger in size, resulting from the need to simultaneously evaluate as many crops and as many factors per crop as possible to quantify and understand the nature of the interactions among factors, both within, and between, crops. Conducting a large experiment, even in a well-equipped research station, may not be desirable because it requires a large experimental area over which homogeneity is difficult to maintain and the chance of experimental failure is generally high.

To maintain a reasonable size, multiple-cropping experiments are usually conducted in two phases: the first phase is an exploratory trial involving a single experiment with a large number of factors and a few levels for each factor; the second phase involves several small experiments each with a few factors and more levels per factor. The experimental techniques for testing a small number of factors per experiment, as required in the second phase trials, are well-documented (Cochran and Cox 1957; Steel and Torrie 1960; Gomez and Gomez 1976) and are not discussed here. On the other hand, the problem of simultaneous testing of a large number of factors in an exploratory trial needs special attention.

With the large number of factors to be tested, even with a reasonable number of levels for each factor, a complete factorial trial would be generally too large. For example, with five factors and three levels for each factor, the total number of complete factorial treatment combinations would be $3^5 = 243$. With the traditional three to four replications, the total number of plots would then become 729 for three replications or 972 for four replications either of which would be too large to be included in a single field experiment. There is clearly a need for a research methodology that can reduce the size of the exploratory trial without sacrificing the assessment of the interaction among factors being tested.

The size of an experiment can be reduced in two ways. One is to reduce the total number of plots by reducing the number of treatments or the number of replications, or both, and the other is to reduce the plot size.

Reduction in the Number of Replications and Treatments

Because the exploratory trial is conducted to assess the nature and the magnitude of the interactions among factors, it is necessarily factorial in nature, i.e., various combinations of the different levels of the different factors are tested simultaneously in the experiment. For factorial experiments, designs have been developed such that the required number of replications can be minimized (partially replicated designs) or such that not all the factorial treatment combinations have to be included (fractional factorial designs).

Partially Replicated Design (PRD). Designs for factorial experiments involving a large number of factors that do not require any replication are available (Cochran and Cox 1957). They are, however, more suited to the type of research that has small inherent variability such as laboratory or industrial research trials. With the large inherent variability that usually characterizes field experiments in agriculture, designs without replication are undesirable. This is especially so for multiple-cropping trials where the expected variability is higher than that for monocrop trials.

For exploratory trials where some reduction in the degree of precision may be acceptable so as to accommodate a large number of factors, designs are needed that require as few replications as possible. A common practice is to use two replications. However, when the number of treatments is so large that the experiment becomes too large even with two replications, the use of PRD offers a promising alternative.

In a PRD, only a portion of the total number of treatments is replicated and experimental error is estimated only from the replicated treatments. For a non-replicated treatment, not only would its degree of precision generally be low, but the loss of the only plot assigned to that treatment is equivalent to the loss of the whole treatment. Thus, the particular set of treatments that should be replicated must be chosen carefully. The following criteria can be used in making the choice of the specific treatments to be replicated.

(a) A treatment that is relatively more important should be replicated to achieve a higher degree of precision and to ensure against its total loss;

(b) A treatment that is prone to "failure" should be replicated to ensure against its total loss; and
(c) The set of treatments to be replicated should properly represent the different levels of the among-plot variability so that the estimate of experimental error, which is obtained only from the replicated treatments, is valid for all treatments.

Fractional Factorial Design (FFD). A reduction in the number of treatments in a factorial experiment can be achieved through the use of an FFD in which only a portion of the complete factorial treatment combinations is tested.

However, by not testing all possible combinations of factors, the main effects of some factors or some interactions may be missed. The effects that can not be estimated must be clearly specified to choose a proper FFD that sacrifices only the unimportant effects. The selection of the effects to be sacrificed is usually based on prior information on the relative sizes of the different effects. If such information is not available, what is usually done is to sacrifice the very high-order interaction effects (e.g., the fourth- or fifth-order interactions) because they are usually expected to be small relative to the rest. More interactions need to be sacrificed as the fraction of the factorial treatments included in the design becomes smaller. The procedure for arriving at a specific set of incomplete factorial treatments that will sacrifice only the prescribed high-order interactions was described by Cochran and Cox (1957). Although the procedure is generally not easy for non-statisticians, it is somewhat simplified if all levels of the test factors are multiples of two. In this case, the number of incomplete factorial treatments can be set at one-half or one-quarter of the complete factorial combinations. For example, the 128 complete factorial treatments in an 8 x 4 x 4 factorial experiment can be reduced to either 64 or 32 fractional factorial treatments corresponding to a fraction of 1/2 or 1/4, respectively. To ensure against an accidental sacrifice of interactions that are known to be large, the design of a fractional factorial trial should always be done in consultation with a competent statistician.

For illustration, the FFD is used that was applied to an exploratory trial conducted at IRRI in 1973 (Harwood 1973) to examine, under varying cultural and management practices, three intercropping systems, namely: corn + mung beans, corn + sweet potatoes, and corn + peanuts. The four test factors and their specific levels for the 3 x 4 x 8 x 8 trial are given in Table 7.1. In the experiment, only 192 treatments were tested. This consists of the 64 fractional factorial treatment combinations from the 4 x 8 x 8 factorial set (Table 7.2), each tested under each of the three rates of nitrogen. The 192 fractional factorial treatments represent a 1/4 fraction of the 3 x 4 x 8 x 8 complete factorial treatment combinations.

Reduction in Plot Size: Continuous Variable Design (CVD)

The second approach to the reduction of experimental size is to reduce plot size by eliminating the need for borders. This can be done with the use of a CVD, a recently developed design applicable only if at least one of the factors to be tested is a continuous or quantitative variable (e.g., plant spacing, fertilizer rate, or irrigation water).

Table 7.1. The four test factors and their corresponding treatment levels tested in an exploratory trial on intercropping with corn

Nitrogen rate	Weed-control method	Corn planting arrangement (no. of plants/ha)	Row Spacing (m)	Crop to be intercropped with corn	Overlap (days)
N_0 : Low	W_0: No weed control	C_0: No corn	-	P_0: No crop	-
N_1 : Medium	W_1: Machete at 0.75 kg/ha AI[1]	C_1: 10,000	1	P_1: Mung beans	-
N_2 : High	W_2: Machete at 1.5 kg/ha AI	C_2: 20,000	1	P_2: Sweet potatoes	65
	W_3: Weed free	C_3: 40,000	1	P_3: Sweet potatoes	80
		C_4: 60,000	1	P_4: Sweet potatoes	95
		C_5: 10,000	2	P_5: Peanuts	65
		C_6: 20,000	2	P_6: Peanuts	80
		C_7: 40,000	2	P_7: Peanuts	95

[1] AI = active ingredient.

Source: Harwood (1973).

Table 7.2. The selected set[1] of 64 treatments composing a 1/4 fractional factorial design from a 4 x 8 x 8 factorial experiment

Corn planting arrangement[2]	Crops to be intercropped with corn[2]							
	P_0	P_1	P_2	P_3	P_4	P_5	P_6	P_7
W_0 : No weed control								
C_0	-	-	-	-	-	x	x	-
C_1	-	x	-	-	-	-	-	x
C_2	x	-	x	-	-	-	-	-
C_3	-	-	-	x	x	-	-	-
C_4	-	-	-	x	x	-	-	-
C_5	x	-	x	-	-	-	-	-
C_6	-	x	-	-	-	-	-	x
C_7	-	-	-	-	-	x	x	-
W_1 : Machete at 0.75 kg/ha AI								
C_0	-	x	-	-	-	-	-	x
C_1	-	-	-	-	-	x	x	-
C_2	-	-	-	x	x	-	-	-
C_3	x	-	x	-	-	-	-	-
C_4	x	-	x	-	-	-	-	-
C_5	-	-	-	x	x	-	-	-
C_6	-	-	-	-	-	x	x	-
C_7	-	x	-	-	-	-	-	x
W_2 : Machete at 1.5/ha AI								
C_0	-	-	-	x	x	-	-	-
C_1	x	-	x	-	-	-	-	-
C_2	-	x	-	-	-	-	-	x
C_3	-	-	-	-	-	x	x	-
C_4	-	-	-	-	-	x	x	-
C_5	-	x	-	-	-	-	-	x
C_6	x	-	x	-	-	-	-	-
C_7	-	-	-	x	x	-	-	-
W_3 : Weed free								
C_0	x	-	x	-	-	-	-	-
C_1	-	-	-	x	x	-	-	-
C_2	-	-	-	-	-	x	x	-
C_3	-	x	-	-	-	-	-	x
C_4	-	x	-	-	-	-	-	x
C_5	-	-	-	-	-	x	x	-
C_6	-	-	-	x	x	-	-	-
C_7	x	-	x	-	-	-	-	-

[1] x refers to treatment being included and "-" not included in the trial.

[2] Factor identification is listed in Table 7.1.

The major feature of a CVD is that the continuous variable is systematically increased in small increments along the field instead of being randomly allocated in rectangular plots as is normally done in traditional field trials. Because the incremental change is gradual and the increase or decrease in the level of the variable is in one direction, border effects are minimized or totally eliminated; resulting in a reduction of the total experimental area required for the trial. At least three types of CVD have so far been developed and used. The first used plant spacing as the continuous variable (Neldar 1962); the second had nitrogen fertilization as the continuous variable (Fox 1973); and the third put irrigation water as the continuous variable (Hanks et al. 1974, 1976; Bauder et al. 1975; Puckridge and O'Toole 1981).

The major advantage of a CVD is the great economy both in the size of the test area required and in the test materials (e.g., fertilizer or water supply) used. Other factors can be easily incorporated in the experiment by applying them at right angles to the original continuous variable. This is illustrated in a layout of a water-management trial with six different rice varieties randomly arranged perpendicular to the simulated water gradients created by the line-source sprinkler system (Figure 7.1).

On the other hand, the CVD has a major drawback in that the continuous variable is not randomized in the layout (i.e., it is systematically arranged with its levels changing gradually over the field). Hence, the traditional statistical analysis of variance for testing significant differences among the levels of the continuous variable is no longer valid. Despite this major disadvantage, however, the useful-

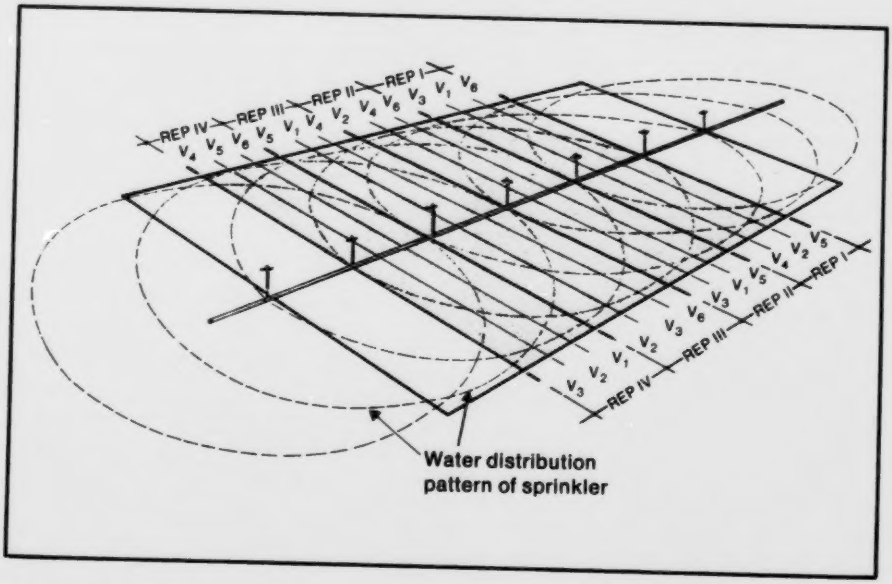
REP IV
REP III
REP II
REP I
V_4 V_5 V_6 V_5 V_1 V_4 V_2 V_4 V_6 V_3 V_1 V_6
V_3 V_2 V_1 V_2 V_3 V_6 V_3 V_1 V_5 V_4 V_2 V_5
REP IV
REP III
REP II
REP I
Water distribution pattern of sprinkler

Figure 7.1. Layout of a continuous variable design with six rice varieties allocated perpendicular to the line-source sprinkler system.

ness of the design has not been totally diminished because of its great savings of experimental resources. Nevertheless, a CVD should be used only if the following conditions exist.

(a) The experiment is an exploratory trial, the main objective of which is to characterize the direction (instead of the absolute value) of the effect of a continuous variable on crop performance.

(b) It is possible to monitor accurately the continuous variable such that its correct levels are assured. For example, in a line-source sprinkler design (see Figure 7.1), soil moisture at the different field positions perpendicular to the irrigation line can be monitored periodically to ensure that the actual moisture levels are as originally intended.

(c) One or more indices can be measured before the simulation of the levels of the continuous variable (e.g., before operating the line-source sprinkler system or before applying fertilizer to detect the presence, if any, of a systematic variability in the test area that may "coincide" with the direction of change in the continuous variable. If such a systematic variability does indeed exist, these indices can be used to make an appropriate adjustment of the treatment effects; for example, they can be used as covariates in an analysis of covariance.

Technology Generation Experiments in Farmers' Fields

Although farmers' fields provide poorer experimental facilities, with fields more heterogeneous and less accessible to researchers than the research stations, they have several attractive features for the conduct of experiments in technology generation. First, they provide a convenient way to sample a wide array of physical and biological conditions that may not be available in research stations; secondly, they provide an opportunity for researchers to have a first-hand exposure to the farmers' needs and constraints; and thirdly, the experimental results are expected to be more realistic and more attuned to the farmers' needs and capabilities.

For on-farm experiments in technology generation, the farms become an extension of the research station, with each farm representing a specific combination of environmental factors. Consequently, it is primarily the physical and biological environment of the farm that is incorporated in the evaluation process. The experiments are designed and managed in a manner similar to those conducted in a research station. That is, the planning and implementation of an experiment are done almost exclusively by researchers with minimal, if any, participation by the farmers. Thus, most of the existing experimental procedures for conducting experiments in research stations are applied to technology generation trials that are conducted in farmers' fields. However, because of the several distinctive features of the fields relative to the research station (discussed in Chapter 6), and because of the need to conduct the experiment on more than one farm, the usual research station methodology needs to be modified to suit better the requirements of an on-farm technology generation experiment. Some of these modifications and the guidelines for their implementation are described here.

Selection of Test Farms

For an experiment in a research station, the choice of a specific field for the conduct of the experiment is simple because of the fairly uniform experimental fields. For an on-farm technology generation experiment, however, the selection of appropriate test farms and fields within a farm is an important consideration because of the generally large variability among farms and fields within a farm.

The step-wise procedures for selecting the test farms and the test area within each farm are as follows:

Step 1 - Based on available climatic data, select one or more locations (i.e., contiguous farm areas) that satisfy the specific test environment in which the selected technologies are to be applied.

Step 2 - Based on soil maps of the locations selected in step 1, identify the sub-areas that most closely satisfy the specific soil characteristics required by the test environment. If an adequate soil map is not readily available, a competent soil scientist should visit the area to pinpoint sub-areas that have the required soil characteristics.

Step 3 - Within the sub-areas identified in step 2, select specific farms that have the topography, landscape, and water regime approximating the test environment. During this same visit, observe other factors relevant to the experiment such as the farmer's current cropping pattern, the existing weed population, and the incidence of pests and disease.

Step 4 - From the qualified farms selected in step 3, select those with attributes that give tne highest chance of success for the experiment, such as the willingness of the farmer to provide land for experimental purposes, accessibility of the farm, and availability of resources required in the experiment.

Step 5 - From the farms selected in step 4, select fields in each farm based on features that will facilitate experimentation such as suitable size and shape of the field and specific field location.

The procedure for the selection of the farms and fields for a technology generation experiment is a purposive technique and not a statistical one, in that the farmers' fields are selected to satisfy a predetermined set of test conditions to represent different types of test environment not found in research stations. Consequently, the number of farms included in a test is equal to the number of environments under which the technology is to be tested. This is in contrast to technology verification experiments in which the farms are selected at random to represent the average farm conditions in the area, and the appropriate sample size (number of test farms) is thus chosen to achieve a prescribed level of precision (see Chapter 8).

Experimental Design and Layout

The lack of experimental facilities in farmers' fields generally necessitates keeping the size of experiment small and the experimental design simple. The same procedures, as those discussed earlier in this chapter for reducing the size of a research station experiment, are applicable to on-farm experiments for technology generation.

The bases for the determination of plot size need not differ from those used in the research station, and similar plot sizes can often be used. On the other hand, plot shape may have to be adjusted to suit the irregular shape of the farmer's field and the manner in which land has been leveled.

If the size of the selected field is larger than the area required for the whole experiment, the simplest alternative is to block out the exact area needed for the experiment in a regular size and shape so that the laying out of plots is facilitated. On the other hand, if the size of the selected field is too small to accommodate the whole experiment, plots with different replications may be placed in different fields but all plots of the same replication must be accommodated in the same field.

Data Collection

All data normally collected in a research-station experiment are usually collected in an on-farm experiment for technology generation. Moreover, the same considerations for choosing the specific sampling and measurement techniques used in research station experiments also apply to on-farm experiments. However, because a suitable sampling technique depends upon the particular measurement technique employed, modifications of the sampling technique may be necessary if the measurement technique used in the on-farm trial is different from that used in the research station trial. For example, the minimum harvest area per plot of 5 m^2 prescribed for rice field experiments is based on the more-detailed manner in which harvest samples are generally processed in the research station. If the processing of harvest samples in an on-farm trial is not as carefully executed (e.g., without the use of thresher or drier), then the harvest area should be larger than 5 m^2.

The proper choice of a specific set of data to be collected in a given trial is critical. Too few data may deprive the researcher of a clear understanding of the effects of treatment, whereas too much data can strain the researcher's limited resources and may result in a sacrifice of precision in the data measured.

In addition to those data traditionally collected in research station experiments, the following data should be collected for an on-farm technology generation experiment.

Characterization of the Test Farm. Experimental fields in a research station are generally well documented in terms of soil, topography, irrigation water, and the history of crops grown and of nutrients applied. Thus, there is usually no need to characterize each field in detail for each and every experiment conducted in a research station. On the other hand, similar data are usually not available for farmers' fields. Consequently, all environmental factors considered important in determining crop yield must be recorded for the experimental field of each test farm. The minimum set of data that should be measured is described in Table 7.3.

Table 7.3. The minimum set of characteristics of a test farm that should be recorded in an on-farm technology generation experiment

Item	Data required
Location	Address or coordinates
Landscape	Position in landscape, i.e., knoll, bottomland, sideslope, etc.
Slope	Shape and gradient
Soil surface	Depth and colour
Soil reaction	pH
Organic matter	% organic matter
Available nutrients	Phosphorus and potassium (ppm)
Crop history	Crops grown last year
Fertilizers applied	Kind and amount applied last year
Irrigation water	Type and availability

Source: Adapted from PCARR (1978).

Climatic Data. Most research stations either have their own well-equipped weather station to monitor climate or have at least one weather station nearby operated by another agency, so weather data need not be collected by researchers for each research station experiment. On the other hand, for an experiment conducted in farmers' fields, the researcher indeed may need to collect climatic data if no weather station exists in the proximity of the farms (Table 7.4).

Pest Damage. The specific type of insects, diseases, and weeds prevailing in the farmers' fields may be quite different from those generally encountered on the research station. Pests must be properly identified and crop damage monitored. Moreover, crop damage caused by rats is usually more severe in farmers' fields than in research stations, due to

Table 7.4. Climatic data that should be recorded in an on-farm technology generation experiment

Item	Data required
Rainfall	Daily total
Solar radiation and sunshine	Daily total
Relative humidity	Daily minimum and maximum
Temperature	Daily minimum and maximum
Wind speed	Daily minimum, maximum, and direction

Source: Adapted from PCARR (1978b).

the lack of extensive rat control procedures in farmers' fields. Also, experimental crops on farmers' fields are generally more prone to attacks by rats because they are planted or harvested "out-of-season" relative to those on the rest of the farm. To improve the accuracy of crop data from plots that are affected by rats, the degree of rat damage for each experimental plot should be measured so that adjustment can be made for rat damage through the use of covariance analysis (Gomez and Gomez 1976).

Data Analysis

Many statistical and analytical procedures are appropriate for both research station and on-farm technology generation trials. However, because the latter are almost always conducted on more than one farm, there is an additional requirement for combining experimental data over several farms so that the effects of interaction between treatment and farm can be critically examined.

The need for combining data over a series of trials is not unique to multiple-cropping experiments conducted in farmers' fields. For example, in monocrop research, it is not uncommon to conduct varietal or fertilizer trials, at several research stations for several crop seasons or years prior to selecting the best variety or fertilizer practice. Statistical techniques are well established for combining data over a series of experiments, either over space or time or both (Cochran and Cox 1957; Finlay and Wilkinson 1963; and Sutjihno 1968). However, for on-farm technology generation experiments, the primary objective for testing across farms that represent different environments is to assess not only the presence, but also the nature of, the interaction between technology and environment. The techniques suitable for the examination of the nature of these interactions need added emphasis.

The procedure for combining data over several farms is illustrated with data from an experiment using a randomized complete-block design with three replications in each of four farms (Table 7.5). The step-by-step procedures for data analysis are as follows:

Step 1 - Perform a combined analysis of variance following the procedure outlined in Cochran and Cox (1957).

Comment: The results (Table 7.6) show a highly significant interaction between farm and treatment, indicating that the treatment effects were not consistent over the farms.

Step 2 - Perform a test of significance for the comparison of treatment means, separately for each farm.

Comment: The results (Table 7.7) indicate that in farm 4, where yields were generally high in all treatments, there was no significant difference among treatments. In farm 2, where the yield of the untreated check was very low (0.53 t/ha), all four weed-control methods showed significant and large yield increases. In farm 1, where the yield of the untreated check was also very low (0.27 t/ha), not all weed-control methods were found effective, i.e., only

Table 7.5. Grain yield of dry-seeded rice test under five weed-control methods in four farms: Iloilo, Philippines, 1978-79 crop year

Farm No.	Rep	Grain yield (t/ha)				
		Butachlor + Proponil	Butralin + Proponil	Proponil alone	Hand-weeded twice	Untreated check
1	I	5.5	0.6	0.2	5.7	0.3
	II	4.8	2.5	0.1	5.2	0.2
	III	5.3	1.2	0.4	4.9	0.3
2	I	5.6	6.8	5.7	5.4	0.4
	II	5.8	3.1	5.7	4.8	0.6
	III	6.0	4.4	5.1	4.0	0.6
3	I	1.8	3.3	2.1	2.9	1.4
	II	2.4	3.7	3.0	1.1	0.7
	III	3.1	2.9	2.4	4.0	1.6
4	I	5.1	3.7	3.6	5.1	2.8
	II	5.4	4.6	4.2	4.7	4.2
	III	5.6	5.0	4.5	5.2	5.8

Source: Department of Agronomy, IRRI; cited with permission from K. Moody.

Table 7.6. Combined analysis of variance for rice yield[1]

Source of variation	df	SS	MS	F
Farms	3	60.8298	20.2766	25.1**
Replications within farms	8	6.4760	0.8095	
Treatments	4	73.7773	18.4443	35.1**
Farm x treatment interaction	12	69.8160	5.8180	11.1**
Pooled error	32	16.8307	0.5260	
Total	59			

[1] Data are from Table 7.5
CV = 21.0%

treatments 1 and 4 were shown to increase yield significantly. In farm 3, the effects from weed control, if any, were relatively small for all methods tested.

These results indicate that the relative performance of the weed-control methods differed greatly among farms. The next step in

Table 7.7. Yield comparison among five weed-control treatments, by farm

Weed-control treatment	Mean yield[1] (t/ha)				
	Farm 1	Farm 2	Farm 3	Farm 4	Av.
Butachlor + Proponil	5.20 a	5.80 a	2.43 ab	5.37 a	4.70
Butralin + Proponil	1.43 b	4.77 a	3.30 a	4.43 a	3.48
Proponil alone	0.23 b	5.50 a	2.50 ab	4.10 a	3.08
Hand-weeded twice	5.27 a	4.73 a	2.67 a	5.00 a	4.42
Untreated check	0.27 b	0.53 b	1.23 b	4.27 a	1.58
Average	2.48	4.27	2.43	4.63	3.45

[1] Data are from Table 7.5 and are averaged over three replications per farm. In each farm, means followed by a common letter are not significantly different at the 5% level of significance.

the data analysis is, therefore, to confirm statistically the hypothesized nature of this interaction, through an appropriate partitioning of the interaction sum of squares.

Step 3 - Partition the sum of squares of the farm x treatment interaction into preselected sets of contrasts or components of comparison (Gomez and Gomez 1976) based on the treatment behavior from farm to farm observed in step 2.

Comment: The large differences in the effectiveness of the weed-control treatments among the farms, point to two important interaction components, farm x (control vs treated) and farm x (among treated). Both are highly significant (Table 7.8), indicating that both the average response to weeding (i.e., control vs treated) and the relative effectiveness of the four weed-control methods (i.e., among treated) varied significantly among farms. Further partitioning based on farms is needed.

Observations made from Table 7.7 indicate that the difference among treatments 1 to 4 was not significant in farms 2, 3, and 4 but was significant in farm 1. Also, there was a significant difference in the average response to weeding between farms 1 and 2 but not between farms 3 and 4.

From these observations, the corresponding interaction components could be constructed as follows:

a) (farm 1 vs farms 2, 3, 4) x (among treated) and (among farms 2, 3, 4) x (among treated); and

b) (farm 1 vs farm 2) x (control vs treated) and (farm 3 vs farm 4) x (control vs treated).

The results of statistical tests of significance on these components (see Table 7.8) confirmed the hypothesis derived from visual observations described above.

Step 4 - Relate the nature of the interaction between farm and

Table 7.8. Partitioning of the sum of squares due to farm x treatment interaction of Table 7.6

Source of variation	df	SS	MS	F
Farm x treatment interaction	12	69.8160	5.8180	11.1**
Farm x (control vs treated)	(3)	23.6535	7.8845	15.0**
(Farm 1 vs farm 2) x (control vs treated)	(1)	4.3663	4.3663	8.3**
(Farm 3 vs farm 4) x (control vs treated)	(1)	1.2979	1.2979	2.5ns
(Farms 1, 2 vs farms 3, 4) x (control vs treated)	(1)	17.9893	17.9893	34.2**
Farm x (among treated)	(9)	46.1625	5.1292	9.8**
(Farm 1 vs farms 2, 3, 4) x (among treated)	(3)	40.5875	13.5292	25.7**
(Farms 2, 3, 4) x (among treated)	(6)	5.5750	0.9292	1.8ns

treatment to the relevant environmental factors in each farm, to gain a better understanding of the influence of these factors on the effectiveness of the treatments tested.

Comment: A likely reason for the large interaction between treatment and farm in such trials is the difference in the intensity and population of weeds prevailing on the different test farms. Weed incidence should be examined in relation to the observed differential performance of the treatments from farm to farm.

Total weed weight in the unweeded plots was very small in farm 4 relative to the other farms (Table 7.9). This could be the reason why, in farm 4, yield of the control treatment was relatively high and not much yield response to weed control was observed (see Table 7.7). When weed weights were correlated with grain yields over the different weed-control treatments, separately for each farm, significant results were indicated only with total weed weight and grasses, and only in farms 1 and 2. The difference in the responses of the various weed-control treatments in farms 1 and 2 could be attributed to their relative effectiveness in controlling grasses. For farm 3, although none of the correlations was significant at the 5% level of significance, the one between yield and weight of broadleaves was close to being significant with $r = -0.86$. The weight of broadleaves in unweeded plots of farm 3 was the highest among all farms. It seems that, in farm 3, the weed-control treatments were somewhat more effective in controlling broadleaves than grasses; and hence, yield of treated plots was not

Table 7.9. Contribution of weed weight data to the explanation of yield differences among weed-control treatments on different farms

	Weed weight[1] (g/m^2)					
Farm No.	Butachlor+ Proponil	Butralin+ Proponil	Proponil alone	Hand-weeded twice	Untreated check	Correlation coefficient with yield
Broadleaves						
1	7.8	9.6	4.0	0.4	0.0	0.07ns
2	16.8	26.8	5.8	0.2	13.8	-0.06ns
3	0.2	4.2	9.4	3.4	32.2	-0.86ns
4	0.2	1.2	0.0	0.4	2.0	-0.38ns
Grasses						
1	20.2	224.0	461.2	6.2	696.0	-0.90*
2	20.8	27.2	10.8	30.0	390.6	-0.98**
3	173.0	164.0	328.0	25.6	387.0	-0.67ns
4	6.4	8.0	28.4	4.8	40.8	-0.73ns
Sedges						
1	0.0	57.0	63.4	9.8	132.2	-0.87ns
2	6.8	39.8	2.6	8.8	17.6	-0.22ns
3	3.6	29.2	14.2	3.4	11.2	0.44
4	0.6	0.6	8.0	0.4	6.6	-0.78ns
Total						
1	28.0	290.6	528.6	16.4	828.2	-0.90*
2	44.4	93.8	19.2	39.2	421.8	-0.98**
3	176.8	197.4	351.6	32.4	430.4	-0.66ns
4	7.2	12.2	45.2	5.8	49.6	-0.81ns

[1] Measured at 62 days after emergence (yield data are from Table 7.7).

Source: Department of Agronomy, IRRI; cited with permission from K. Moody.

much higher than that in control plots. On the other hand, it is not clear why the yield of treatment 4 (i.e., hand-weeded twice) in this same farm was not higher than that of other weed-control treatments even though the weeds in these plots were much less than in other plots.

Technology Generation Experiments Through Computer Simulation

In multiple-cropping research in which several crops and many factors need to be evaluated simultaneously, the computer is an attractive tool for handling such large and complex experiments. With its great capacity for data storage, coupled with its ability to access and process stored data quickly, the computer can handle a large number of factors and levels per factor with greater speed and at less cost than that generally possible through actual field experiments. Many different types of experiments can be conducted in computers, this section focuses on the technique of computer simulation by using crop production models to simulate the behavior of crop productivity in field experiments.

The procedure for applying computer simulation in multiple-cropping research can be divided into three main components: the development of a crop-production model; the verification of the model; and the selection of the optimum production strategy. In succeeding sections, each of these components is discussed and some of the major constraints to the practical application of this technique are indicated.

Development of a Crop-Production Model

A model is an abstract representation of a real phenomenon such that the behavior of the former closely resembles that of the latter (Manetsch and Park 1974). For multiple cropping, the real productivity of various cropping patterns over a wide range of growing conditions is represented in its abstract form as a crop-production model, which is a mathematical function describing the relationship between crop productivity, the environment, and management variables.

Many types of crop-production model have been developed in the last two decades. Some are very detailed and are able to describe the rate of growth and development of plants on a daily basis, such as those of Duncan et al. (1967) and Curry and Chen (1971) for corn, Baker et al. (1972) and Stapleton et al. (1973) for cotton, Miles et al. (1973) for alfalfa, and Trenbath (1974) for wheat. Other models are simpler such as those of Angus and Zandstra (1979) for rice, Garcia (1979) for corn, and Santos (1980) for tomatoes. The tomato model, for example, developed by Santos assumes that the fruit yield is influenced by the environment and management practices in the following manner:

$$Y = Y_o \prod_{i,j} (1 - R_{ij}) \qquad [7.1]$$

where Y is predicted yield, Y_o is maximum yield (i.e., yield under ideal environment and optimum management practices), and R_{ij} is yield reduction expressed as a fraction of Y_o, caused by stress in the ith environment or management factor at the jth growth stage.

The model, equation 7.1, specifies that each environmental and management stress reduces maximum yield by a given percentage, and that the final yield is computed as the yield under ideal environment and management minus the cumulative yield reduction due to all stresses.

The eight indices of the environmental and management factors considered by Santos in his tomato model are available nitrogen, available phosphorus, available potassium, nematode damage, bacterial wilt damage, temperature, solar radiation, and soil water content (Table 7.10). The specific yield reduction equation needed for the estimation of each R_{ij} of equation 7.1 is given in Table 7.10. Some of the yield reduction equations, such as those for available nitrogen,

Table 7.10. Yield reduction equations due to different types of stress based on eight indices of the environmental and management factors considered in the tomato model

Environmental and management index	Growth stage[1]	Yield reduction equation		
Available nitrogen (N)	all	$100-1.045N + 0.00272N^2$	for	$0 \leq N > 180$ kg/ha
		0	for	$180 \leq N > 280$ kg/ha
		$100-1.583N + 0.00429N^2$	for	$280 \leq N > 370$ kg/ha
		100	for	$N \geq 370$ kg/ha
Available phosphorous (P)	all	$100-2.528P - 0.0158P^2$	for	$0 \leq P > 70$ kg/ha
		0	for	$70 \leq P > 152$ kg/ha
		$100-3.236P + 0.1688P^2$	for	$152 \leq P > 192$ kg/ha
		100	for	$P \geq 192$ kg/ha
Available potassium (K)	all	$100-1.314K + 0.00496K^2$	for	$0 \leq K > 130$ kg/ha
		0	for	$130 \leq K > 500$ kg/ha
		$100-0.522K + 0.00062K^2$	for	$500 \leq K > 842$ kg/ha
		100	for	$K \geq 842$ kg/ha
Nematode damage (Q)	2	$21.87Q - 21.87$	for	$Q = 1, 2, 3, 4$ and 5
Bacterial wilt damage (B)	2	$25B - 25$	for	$B = 1, 2, 3, 4$ and 5
Temperature (T)	3	100	for	$T < 15^\circ C$ or $T > 33.73^\circ C$
		0	for	$15 \leq T > 24^\circ C$
		$-7.2959T + 0.3043T^2$	for	$24 \leq T \geq 33.73^\circ C$
Solar radiation (S)	1	100	for	$S < 30$ langley/day
		$10-0.20388\ (S-30)$ $+\ 0.000478\ (S-30)^2$	for	$30 \leq S \geq 400$ langley/day
		0	for	$S > 400$ langley/day

	2 and 3	100	for $S < 72$ langley/day
		$10-0.27222\ (S-72) + 0.000441\ (S-72)^2$	for $72 \leq S \geq 650$ langley/day
		0	for $S > 650$ langley/day
	4	100	for $S < 72$ langley/day
		$10-.04760\ (S-72) + 0.000620\ (S-72)^2$	for $72 \leq S \geq 840$ langley/day
		0	for $S > 840$ langley/day
Available water (W)*	1	$100-3.257W + 0.0265W^2$	for $0 \leq W > 60\%$
		0	for $60 \leq W \geq 120\%$
		$100-1.420W + 0.00529W^2$	for $120 < W \geq 269\%$
		100	for $W > 269\%$
	2	$100-4.300W + 0.0440W^2$	for $0 \leq W > 60\%$
		0	for $60 \leq W \geq 100\%$
		$100.1.556W + 0.00614W^2$	for $100 < W \geq 254\%$
			$W > 254\%$
	3	$100-3.249W + 0.0260W^2$	for $0 \leq W > 70\%$
		0	for $70 \leq W \geq 100\%$
		$100-1.540W + 0.00617W^2$	for $100 < W \geq 249\%$
		100	for $W > 249\%$
	4	$100-5.292W + 0.0540W^2$	for $0 \leq W > 70\%$
		0	for $70 \leq W \geq 100\%$
		$100-1.123W + 0.00326W^2$	for $100 < W \geq 345\%$
		100	for $W > 345\%$

---

[1] Growth stage when the stress occurred: 1 = seedling stage; 2 = vegetative stage; 3 = flowering and fruiting stages; and 4 = fruit enlargement stage.

$$* \ W = \left(\frac{\text{actual soil water content - water content at permanent wilting point}}{\text{water content at field capacity - water content at permanent wilting point}}\right) \times 100$$

Source: Santos (1980).

available phosphorous, and available potassium, are the same for all growth stages, whereas others, such as those for nematode, bacterial wilt, and temperature, are assumed to be important only at a particular growth stage; and those for solar radiation and water availability varied widely from one growth stage to another. The data required for the computation of each index are listed in Table 7.11.

Whereas most of the crop-production models have been developed on a per crop basis and are more suited for simulation experiments in monocrop, the same models, under some assumptions, can be adequately used as building blocks for a multiple-cropping model. For example, the tomato model of Santos (1980) and the corn model developed by Garcia (1979) together can simulate the performance of a corn - tomato sequential cropping pattern. Once the length of maturity and the planting date for each crop are specified, the performance of each crop component can be computed separately using the respective single-crop model.

This procedure, however, for using single-crop models as building blocks for a multiple-cropping model is valid only under the assumption that there is no complementary nor competitive relationship among the component crops. This is more likely to be satisfied under sequential cropping than under intercropping, and, thus, the procedure is not likely to be applicable to intercropping.

Table 7.11. Data on the environmental and management factors needed for the verification of Santos' tomato model

Index	Data required
Available nitrogen	Percentage organic matter Added nitrogen
Available phosphorus	Native phosphorus pH Added phosphorus
Available potassium	Native potassium Added potassium
Nematode damage	Nematode infection rating index[1]
Bacterial wilt damage	Bacterial wilt infection rating index[1]
Temperature	Average daily temperature
Solar radiation	Total daily solar radiation
Available water	Daily rainfall Irrigation water applied Daily actual pan evaporation Soil texture

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[1] The damage indices are integer values from 1 (damage free) to 5 (severely damaged).

Model Verification*

By definition, a model is said to be valid if its behavior resembles closely that of the real phenomenon it is designed to simulate. For a multiple-cropping model, this is equivalent to showing that its predicted yield closely resembles the actual field performance under a wide range of environmental conditions. Hence, to verify a multiple-cropping model, several data sets are needed, each having both the performance data of the specified cropping pattern and the information on the environments under which the cropping pattern was grown and the management practices employed. For example, to verify the validity of Santos' tomato model, data on all the characters related to the environmental and management factors listed in Table 7.11 must be available for each crop performance. Whenever data on one or more variables are missing, the whole set becomes useless in the verification process and has to be discarded. For a multiple-cropping model, the requirement is not only that the data set is complete for one crop but also that it must be complete for all crops in the cropping pattern. So, unless trials are specifically planned and conducted to gather the needed data for model verification, the chance of finding suitable data sets with all the specified variables measured is small, even for a single crop. It becomes much smaller for a specific cropping pattern or a combination of crops. Special trials for the gathering of data for model verification are extremely costly to conduct and are not likely to be within the limited research resources existing in developing countries. Therefore, the data requirement for verification of a multiple-cropping model is very difficult to satisfy in practice, and model verification is generally done, if at all, at the monocrop level.

The process of model verification begins with the identification of as many field experiments as possible that involve the particular crop of interest in the cropping pattern, and that have a complete data set on the environmental and management factors required for that crop. Performance data from these experiments are then compared with those of the corresponding predicted values derived from the model. For the tomato model, for example, the observed and predicted yields under 35 different combinations of environmental and management factors are given in Figure 7.2. Of the variability in the observed tomato yields, 74% was accounted for by the model.

Selection of the Best Production Strategy

Once a crop-production model has been properly verified, it is expected to be able to predict adequately the performance of a given crop under any set of specified environmental and management practices. It can also be used to identify the best management practices under a given set of environmental conditions and farm constraints, because, given the farm resources and the expected physical and biological environments of a particular farm, the model can select, from among many alternative production strategies, that which will best satisfy the farmer's objectives.

The procedure, developed by Gomez (1974), for identifying the crop-production strategy that maximizes farm profit will be used for illustration. The selection process (Figure 7.3) consists of the following steps:

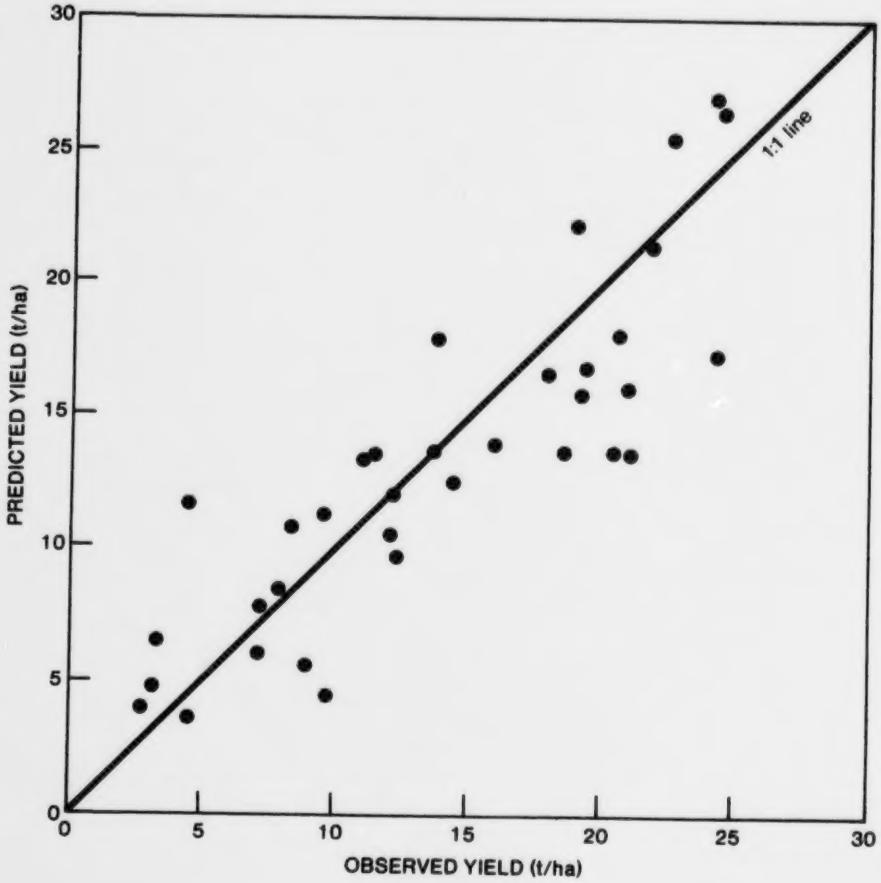

Figure 7.2. Comparison between the predicted yields of tomato based on the computer simulation model of Santos (1980) and the actual experimental yields, under 35 different combinations of environmental and management factors.

Step 1 - For each crop, select the production package that maximizes profit;

Step 2 - For each growing season, allocate the farm area to each crop-production package such that the productivity of farm resources is maximized; and

Step 3 - Repeat steps 1 and 2 for each growing season of the year.

This procedure does not directly select the best cropping pattern but rather it selects the best crop for every growing season of

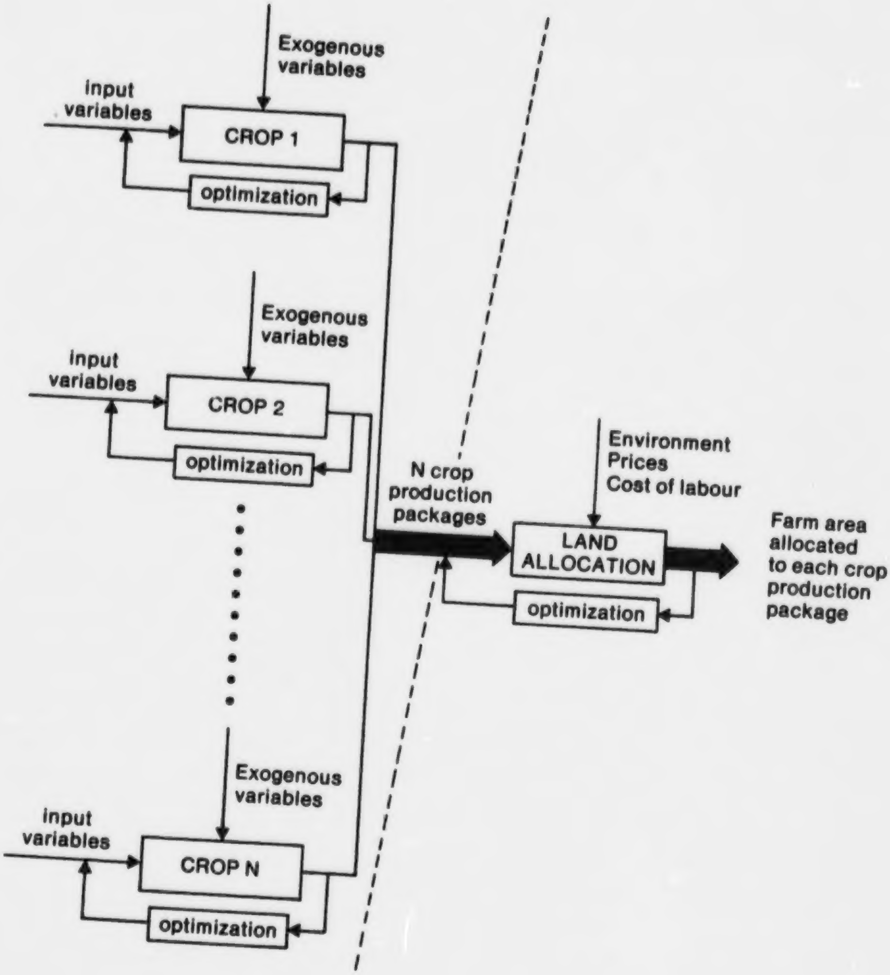
Exogenous variables
input variables
CROP 1
optimization
Exogenous variables
input variables
CROP 2
optimization
Exogenous variables
input variables
CROP N
optimization
N crop production packages
Environment
Prices
Cost of labour
LAND ALLOCATION
optimization
Farm area allocated to each crop production package

Figure 7.3. A two-stage computer simulation process for optimizing crop production in small farms. The two stages are separated by the dotted line (after Gomez 1974).

the year. The selected crops are then combined to form the best sequential cropping pattern for the farm.

As in the development of the crop-production model, the procedure for selecting the best production strategy is suited primarily to sequential-cropping patterns in which the interaction among crop components can be conveniently ignored. This simplified procedure is not suitable for intercropping in which the interaction among crops is expected to be large.

Problems and Difficulties

In spite of the many attractive features of the computer-simulation technique for multiple-cropping research, it has not been used widely in the developing countries of Asia. Two reasons for this are the scarcity of data for both model development and model verification and the lack of adequate computer facilities and know-how in these countries.

For model development, information on the mode of action and the effects of important environmental and management factors on crop performance obtained is necessary. For model verification, data on actual crop performance obtained under a wide range of growing conditions plus a complete record of the environmental and management variables under which each crop was grown are needed.

The information and data required for both model development and model verification are substantial and are not easily available even for monocrops. The situation becomes more acute for multiple cropping.

Moreover, once a mathematical model has been developed, the simulation experiment to select the best production strategy needs to be done in a fairly large and sophisticated computer. Also, the translation of the mathematical model into a computer language requires a level of programing capability that is generally not present among agricultural researchers, especially so in the developing countries of Asia. Although a well-trained computer programmer can be recruited as a member of the research team, there is still a need for the other team members to have a certain degree of familiarity with computer programing to facilitate communication with the computer programmer.

Clearly, neither the needed computer facility nor the programing capability required in computer simulation work are available in most research stations in the developing countries of Asia.

CHAPTER 8: EXPERIMENTS FOR TECHNOLOGY VERIFICATION

Experiments for technology verification are designed to verify the superiority of newly developed technology over the farmer's existing practice in his own farm environment. This is necessary since farmers adopt only those technologies clearly seen as superior to their own. These experiments are characterized by several distinctive features.

Farmers' Fields as Research Site. The superiority of a new technology over that of a farmer must be evaluated under the actual environment of the farmer himself. In this way, the new technology and the farmer's practice are compared, not only under the same environment but also under that in which the new technology is to be adopted. This improves both the accuracy of the comparison and its significance. Moreover, it is only by locating the experiment in the farmer's field that his actual practice can be properly assessed and evaluated.

Evaluation of the Farmer's Capability and Willingness to Adopt the New Technology. Even if a new technology is more productive than the farmer's practice, economic and social constraints could prevent him from adopting it. For example, either lack of capital to buy new inputs or non-availability of labour to perform the additional operations required by the new technology could greatly hinder its adoption by farmers. The experiments provide a good opportunity to evaluate such economic and social constraints. For example, when new technology involves an operation unfamiliar to the farmer, such as the seeding of mung beans after rice on an uncultivated paddy, the farmer can be asked to perform this himself. Its feasibility can then be evaluated in terms of the actual labour required and the farmer's willingness to perform the operation.

Tests on Several Farms. Different farms, even in a supposedly homogeneous area, vary in their physical, biological, and socioeconomic environments as well as in their production practices. Thus, experiments must be conducted in a sufficiently large number of farms in order to truly represent the varying conditions.

Evaluation of Intermediate Levels of Technology. A new production technology usually consists of several component technologies each considered important in increasing productivity, for example, three components such as an improved variety, an increase in fertilizer level, and an improvement in weed control. When the productivity of the new technology is compared to that of the farmer's practice, however, only the combined effect of all of its components can be assessed. The contribution to the increase in productivity of each of the component, i.e., variety, fertilizer, and weed control, can be measured only with the testing of production technologies that are intermediate between that of the new production technology and the farmer's practice. These intermediate technologies are constituted by the factorial combination of the component technologies, each of which may take anyone of two levels: the farmer's or the new technology. The productivity of each of these intermediate technologies can then be evaluated and compared with that of the new technology and of the farmer's practice.

Because of these requirements, the traditional research techniques, developed mainly for technology generation experiments, do not apply. New procedures specifically suited for technology verification are needed. This chapter describes primarily research techniques for technology verification and also touches on the procedure for conducting experiments that combine the features of technology generation and verification.

Research Methodology for Technology Verification

A research methodology for technology verification that has been developed and successfully tested in rice is the yield constraints approach (Gomez et al. 1973; De Datta et al. 1978; IRRI 1979). Originally designed to explain quantitatively why rice yields in farmers' fields are much lower than those obtained on research stations, the conceptual model on which the approach is based is illustrated in Figure 8.1. The model breaks the difference between the experiment station yield and the actual farm yield (i.e., the total yield gap) into three distinct parts by introducing two intermediate yield levels; the first representing the potential farm yield (i.e., the yield obtainable in a farmer's field using the new technology) and the second representing the economic farm yield (i.e., the part of the potential farm yield that is profitable to produce).

The first part of the total yield gap, yield gap I, is the difference between experiment station yield and potential farm yield, which is due to deficiencies in the farm environment beyond the farmer's capability to modify. The presence of a large yield gap I indicates that the new technology developed in the experiment station has a low degree of adaptability to the actual farm conditions.

The second part of the total yield gap, yield gap II, is the difference between potential farm yield and economic farm yield, which represents the portion of the potential farm yield uneconomical for the farmer to produce under his farm conditions. Although the new technology gives higher yield than that of the farmer, its profitability is lower. The presence of yield gap II indicates the lack of proper economic consideration in the development of the new technology.

The third part of the total yield gap, yield gap III, is the difference between economic farm yield and actual farm yield, and represents the additional yield that the farmer can economically produce on his farm. Its presence indicates the non-adoption by farmers of a production technology that has been shown to give both higher yield and higher profit than his own.

The yield constraints approach can identify and measure the factors (or constraints) responsible for yield gaps II and III, through controlled agronomic experiments in farmers' fields and farm surveys. By conducting controlled experiments, the contribution of the physical

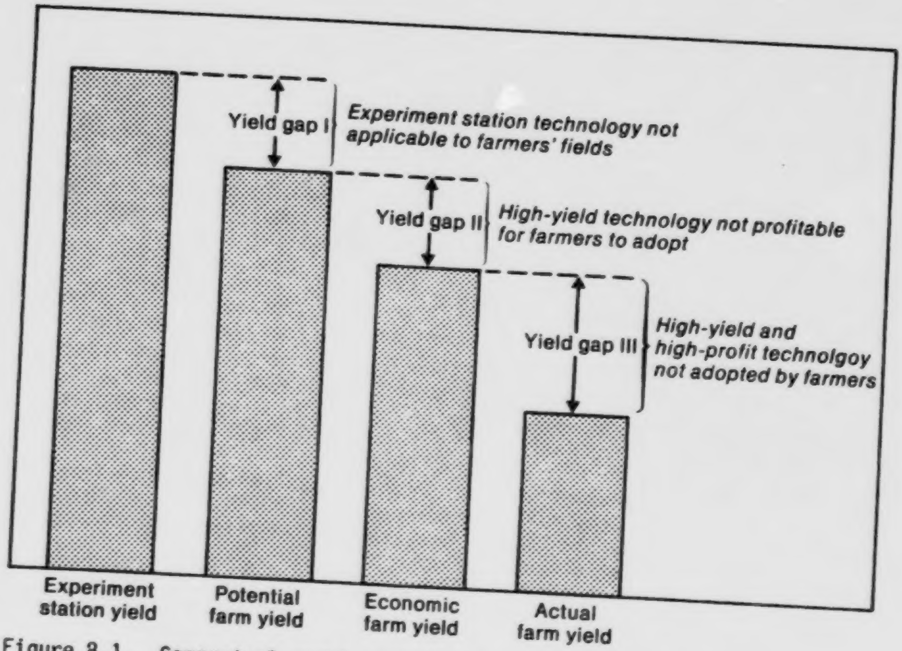
Yield gap I
Experiment station technology not applicable to farmers' fields
Yield gap II
High-yield technology not profitable for farmers to adopt
Yield gap III
High-yield and high-profit technolgoy not adopted by farmers
Experiment station yield
Potential farm yield
Economic farm yield
Actual farm yield

Figure 8.1. Conceptual model explaining the gap between experiment station yield and actual farm yield (adapted from Gomez 1977).

and biological constraints to the yield gap is measured; and, by conducting farm surveys (see Chapter 9), the socioeconomic and institutional constraints are identified. The objectives of the yield constraints approach are the same as those for technology verification described earlier in this section. However, the procedure for the yield constraints approach has been devised solely for monocropping. A modified version is thus needed for use with multiple-cropping technologies.

Target Area

A geographical area where the crop productivity is perceived to have a good potential for improvement through the introduction of new technologies is referred to as a target area. Its coverage or boundaries must be selected carefully such that the farms within each target area are homogenous with respect to their bio-physical and socioeconomic environments. Such homogeneity is essential if a reasonable number of packages of new technology are to be tested against a reasonable number of farmers' cropping patterns. To determine the coverage of a target area, the following guidelines are suggested.

First, major determinants of the homogeneity in the biophysical environments are water availability and the main crop. Thus, the target area should be defined such that it is confined to farms with the same main crop (e.g., lowland rice, corn, or coconuts) and a common situation in terms of water availability (e.g., water available for at least nine months, six to nine months, or less than six months per year).

main crop (e.g., lowland rice, corn, or coconuts) and a common situation in terms of water availability (e.g., water available for at least nine months, six to nine months, or less than six months per year).

Second, the coverage of a target area need not be contiguous, provided that homogeneity, as defined, is satisfied. Although a non-contiguous area may be advantageous in that its area and farmer clientele can be enlarged, in practice, one that is contiguous and is within the same administrative unit (i.e., township or province) is more commonly used because the socioeconomic environment is expected to be more uniform and the distance among test farms is shorter.

Test Factors

The major objectives of the on-farm controlled experiment for technology verification are to measure the difference in productivity between that of the new technology and that of the farmer's practice, and to identify and quantify the contribution of the important components of technology to this yield difference.

These objectives are achieved by measuring the yield levels of the new technology, the farmer's technology, and the intermediate technologies between two obtained by a systematic addition or withdrawl of one or more component or test factor.

The number of intermediate technologies that should be tested depends on the number of components of technology that differentiate the new technology and the farmer's; i.e., the larger the number of components, the larger is the number of intermediate technologies that should be tested. To keep a reasonable size of the experiment, the test factors should be restricted to a few important ones. In practice, three to six test factors are generally used, such as fertilization, insect control, weed control, land preparation, and variety (IRRI 1979).

The concept of test factors must be applied only to individual crops and only to those common to both the new and the farmer's technology. For example, when the new technology involves double cropping of rice followed by mung beans and the farmer's technology is a single crop of rice, then the test factors need to be defined only for the particular rice crop that is common to both technologies. On the other hand, when both the new and the farmer's technologies involve the same crop composition, namely, a rice - corn cropping pattern, then two sets of test factors need to be defined -- one for rice and another for corn. The total number of test factors is the sum of the numbers of test factors for the two crops.

Treatments to be Tested

Treatments to be tested in a technology verification trial can be viewed as the factorial combinations of n test factors each having two levels, the high level (prescribed in the new technology) and the farmer's level (practiced by the farmer). The maximum number of treatments, 2^n, represents the complete factorial treatment combinations. With a large number of test factors, the number of complete factorial treatment combinations is also large. For example, with only five test factors, the number of complete factorial treatments is 2^5 or 32, which is generally considered to be too large for an on-farm trial

-- especially as such trials must be conducted in a reasonably large number of farms. However, the testing of the complete set of factorial treatment combinations is necessary only if all possible effects of interaction among the test factors need to be assessed. In practice, not all factors are expected to interact with one another, and even if some do, they are not expected to interact in all possible ways. An appropriate set of incomplete factorial treatments, or specifically a fractional factorial design (described in Chapter 7) can be chosen by sacrificing a specific set of interactions known to be "unimportant". In the case given in Table 8.1, there are four test factors: fertilizer (F), variety (V), weed control (W), and insect control (I). The complete set of factorial combinations consists of 16 treatments so with this particular half set of fractional factorial treatments, all the main effects of each of the four test factors and only three of the six two-factor interactions (FxV, FxW, and FxI) could be estimated. The other three two-factor interactions (VxW, VxI, and WxI), all four three-factor interactions (FxVxW, FxVxI, FxWxI, and VxWxI), and the only four-factor interaction (FxVxWxI) could not be estimated.

In selecting the fractional factorial treatment set, care must be taken to include the two most important treatments namely, the new technology and the farmer's practice. If this is not possible, then one or both of these two treatments must be added to the fractional

Table 8.1. The four sets of treatments in a monocrop yield constraints trial using four test factors: fertilizer (F), variety (V), weed control (W), and insect control (I)

Treatment no.	Factor level[1]				Set of treatments[2]			
	F	V	W	I	Complete factorial	Fractional factorial	Mini factorial	Supple-mental
1	h	h	h	h	X	X	X	X
2	f	h	h	h	X	-	X	-
3	h	f	h	h	X	-	X	-
4	f	f	h	h	X	X	-	-
5	h	h	f	h	X	-	X	-
6	f	h	f	h	X	X	-	-
7	h	f	f	h	X	X	-	-
8	f	f	f	h	X	-	-	-
9	h	h	h	f	X	-	X	-
10	f	h	h	f	X	X	-	-
11	h	f	h	f	X	X	-	-
12	f	f	h	f	X	-	-	-
13	h	h	f	f	X	X	-	-
14	f	h	f	f	X	-	-	-
15	h	f	f	f	X	-	-	-
16	f	f	f	f	X	X	X	X

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[1] h = high level and f = farmer's level.

[2] "-" refers to not tested and "X" for tested.

factorial set chosen.

When no interaction effect is expected to be appreciable, the number of treatments can be reduced to only n + 2 (two more than the number of test factors) by using the mini-factorial design (Gomez 1977). In this design, there are exactly n intermediate technologies between the new technology and the farmer's technology. Each of these intermediate technologies has all test factors, except one, prescribed at the high level and only one test factor set at the farmer's level (see Table 8.1). With this set of treatments, none of the interaction effects can be individually estimated.

In summary, the intermediate levels of technology for testing can be any one or more of the following three possible sets of treatments: the complete factorial, the fractional factorial, and the mini factorial. The choice depends on the number of test factors, the relative sizes of the various interaction effects among test factors, and the resources available. The purpose for including these intermediate levels of technology in the test is to be able to identify the specific test factors responsible for the yield gap and to quantify their individual contributions to that gap. In the estimation of the yield gap itself, only the testing of the two levels of technology is required using a supplemental set consisting of only two treatments -- the new technology and the farmer's technology.

Because field experiments are designed to evaluate not only the total yield gap but also the contribution to the gap of the test factors (main effects as well as the interaction effects) a combination of the different sets of treatments is usually tested in the same target area. From the total number of test farms selected, some are assigned to test the complete factorial treatment set, some to test the mini-factorial treatment set, and the remainder to test the supplemental set. The factors to consider in making such an allocation are discussed under Experimental Techniques (Chapter 8) and Selection of Test Farms (Chapter 9).

To illustrate the construction of the different sets of treatments for use in verification trials involving multiple-cropping technologies, four cases are considered.

Case I: When the New Technology and the Farmer's Practice Involve the Same Cropping Pattern.

Assuming that the common cropping pattern is rice - corn, that there are four test factors for rice (variety, fertilizer, weed control, and insect control), and three test factors for corn (variety, insect control, and land preparation), the total number of factors is seven. A total of 2^7 or 128 treatments would be required for the complete factorial set, which is clearly too large for an on-farm experiment. To reduce the number of treatments to be tested, either the mini-factorial or a fractional factorial set of treatments, or both, can be used. With the seven test factors, the nine mini-factorial treatments are as shown in Table 8.2. The fractional factorial set of treatments can be selected from the following alternatives:

a) For the 1/4 fractional factorial treatments (Table 8.3), all seven main effects and 18 out of the total of 21 two-factor interactions among the seven test factors can be

Table 8.2. The set of nine mini-factorial treatments for a technology verification experiment involving seven test factors in a rice - corn cropping pattern[1]

Treatment No.	Factor level[2]						
	Rice				Corn		
	V	F	W	I	V	I	L
1	f	f	f	f	f	f	f
2	f	h	h	h	h	h	h
3	h	f	h	h	h	h	h
4	h	h	f	h	h	h	h
5	h	h	h	f	h	h	h
6	h	h	h	h	f	h	h
7	h	h	h	h	h	f	h
8	h	h	h	h	h	h	f
9	h	h	h	h	h	h	h

[1] Both the new technology and the farmer's technology involve the same cropping pattern.

[2] V = variety, F = fertilization, W = weed control, I = insect control, and L = land preparation.
f = farmer's level and h = high level.

estimated. The remaining three two-factor interactions that can not be estimated are:

a) $(I_R \times V_C)$ or $(I_C \times L_C)$,
b) $(I_R \times L_C)$ or $(V_C \times I_C)$, and
c) $(I_R \times I_C)$ or $(V_C \times L_C)$;

where the subscript R refers to the rice crop, and C to the corn crop (e.g., I_R refers to the insect control of rice). The two interactions in each of the above pairs are confounded, i.e., their effects can not be separated, so only one of each pair can be estimated whereas the other one must be assumed negligible.

In this set of 32 fractional factorial treatments, the new technology (where all test factors are at the high level) is not represented and must be added giving a total of 33 treatments to be tested instead of 32.

b) In the 1/8 fractional factorial treatments (Table 8.4), all seven main effects and only seven out of the total of 21 two-factor interactions can be estimated. The seven interactions that can be estimated are:

a) $(V_R \times V_C)$ or $(F_R \times I_C)$ or $(W_R \times L_C)$,
b) $(V_R \times I_C)$ or $(F_R \times I_C)$ or $(I_R \times L_C)$,
c) $(V_R \times L_C)$ or $(W_R \times V_C)$ or $(I_R \times I_C)$,
d) $(F_R \times L_C)$ or $(I_R \times V_C)$ or $(W_R \times I_C)$,
e) $(V_R \times F_R)$ or $(W_R \times I_R)$ or $(V_C \times I_C)$,
f) $(V_R \times W_R)$ or $(F_R \times I_R)$ or $(V_C \times L_C)$, and
g) $(V_R \times I_R)$ or $(F_R \times W_R)$ or $(I_C \times L_C)$.

In each of the above sets of three interactions, two

Table 8.3. A set of 32 fractional factorial treatments (1/4 of 2^7) for a technology verification experiment involving seven test factors in a rice - corn cropping pattern[1]

Treatment No.	Factor level[2]							Treatment No.	Factor level[2]						
	Rice				Corn				Rice				Corn		
	V	F	W	I	V	I	L		V	F	W	I	V	I	L
1	f	f	f	f	f	f	f	17	h	h	f	f	f	f	f
2	f	h	h	f	f	f	f	18	h	f	h	f	f	f	f
3	h	f	f	h	f	h	f	19	f	h	f	h	f	h	f
4	h	f	f	f	h	f	h	20	f	h	f	f	h	f	h
5	f	f	f	h	h	h	h	21	f	f	h	h	f	h	f
6	h	h	h	h	f	h	f	22	f	f	h	f	h	f	h
7	h	h	h	f	h	f	h	23	h	f	h	h	h	h	h
8	f	h	h	h	h	h	h	24	h	h	f	h	h	h	h
9	f	h	f	h	f	f	h	25	f	f	f	h	h	f	f
10	f	h	f	f	h	h	f	26	f	f	f	f	f	h	h
11	f	f	h	f	h	h	f	27	h	f	f	h	f	f	h
12	h	h	f	f	f	h	h	28	h	f	f	f	h	h	f
13	h	f	h	f	f	h	h	29	f	h	h	h	h	f	f
14	h	h	f	h	h	f	f	30	f	h	h	f	f	h	h
15	h	f	h	h	h	f	f	31	h	h	h	h	f	f	h
16	f	f	h	h	f	f	h	32	h	h	h	f	h	h	f

---

[1] Both the new technology and the farmer's technology involve the same cropping pattern.

[2] V = variety, F = fertilization, W = weed control, I = insect control, and L = land preparation.
f = farmer's level and h = high level.

of the three interactions in each set must be negligible so the third can be estimated correctly.

In this case, both the farmer's technology and the new technology are represented in the set of 16 fractional factorial treatments. Hence, no additional treatment is required and the total number of treatments to be tested is 16.

Case II: When the Number of Crops is the Same in Both the New and the Farmer's Cropping Pattern but One or More Crop Components Differ.

For example, if the farmer's cropping pattern is rice - corn and that of the new technology is rice - rice, the test factors are specified only for the first rice crop which is common to both patterns. Assuming that the three test factors in the first rice crop are method of planting (i.e., direct-seeded for the new technology and transplanted for the

Table 8.4. A set of 16 fractional factorial treatments (1/8 of 2^7) for a technology verification experiment involving seven test factors in a rice - corn cropping pattern[1]

Treatment No.	Factor level[2]							Treatment No.	Factor level[2]						
	Rice				Corn				Rice				Corn		
	V	F	W	I	V	I	L		V	F	W	I	V	I	L
1	f	f	f	f	f	f	f	9	h	h	f	f	f	f	h
2	h	h	h	h	f	f	f	10	h	f	h	f	f	h	f
3	h	h	f	f	h	h	f	11	h	f	f	h	h	f	f
4	h	f	h	f	h	f	h	12	f	h	h	f	h	f	f
5	h	f	f	h	f	h	h	13	f	h	f	h	f	h	f
6	f	h	h	f	f	h	h	14	f	f	h	h	f	f	h
7	f	h	f	h	h	f	h	15	f	f	f	f	h	h	h
8	f	f	h	h	h	h	f	16	h	h	h	h	h	h	h

---

[1] Both the new technology and the farmer's technology involve the same cropping pattern.

[2] V = variety, F = fertilization, W = weed control, I = insect control, and L = land preparation.
f = farmers' level and h = high level.

farmer's practice), fertilization, and insect control, then the set of $2^3 = 8$ complete factorial treatments and the set of five mini-factorial treatments are as shown in Table 8.5. Because the number of complete factorial treatments is only eight in this case, there is no need to consider the use of fractional factorial treatments.

The choice of the second crop in each plot is determined by the method of planting the first crop. Thus, the second crop is rice if the first crop is direct-seeded rice, and corn if the first crop is transplanted rice.

Case III: When the New Technology Adds One or More Crop to That of the Farmer.

The two examples used as an illustration are a recommended rice - mung-bean cropping pattern tested against the farmer's single crop of rice, and a recommended rice - corn - mung-bean cropping pattern tested against the farmer's rice - corn cropping pattern.

For the first example, only the test factors for the rice crop need to be prescribed. The different sets of treatments can be constructed in the same manner as that in Case II.

For the second example, the test factors are composed of those for the rice and for the corn crops. The various sets of treatments can be constructed in the same manner as that described in Case I.

Table 8.5. Complete factorial and mini-factorial sets of treatments for a technology verification experiment with a recommended rice - rice cropping pattern tested against a rice - corn cropping pattern of the farmer; and with three test factors on the first rice crop

	Treatment description					
	Factor level[1] (1st rice crop)				Set of treatments[2]	
Treatment No.	Method and time of planting	Fertilizer	Insect control	Second Crop	Complete factorial	Mini-factorial
1	h	h	h	rice	x	x
2	f	h	h	corn	x	x
3	h	f	h	rice	x	x
4	f	f	h	corn	x	-
5	h	h	f	rice	x	x
6	f	h	f	corn	x	-
7	h	f	f	rice	x	-
8	f	f	f	corn	x	x

[1] f = farmer's level and h = high level.
[2] "-" refers to not tested and "x" for tested.

Case IV: When There is no Common Crop Between the New Technology and the Farmer's.

When the new technology involves a corn - tomato cropping pattern and the farmer's technology involves an upland rice - mung-bean cropping pattern, no test factor needs to be prescribed and only the supplemental set, consisting of two treatments (i.e., the new technology and the farmer's technology), need to be tested.

Experimental Technique

The field plot techniques for conducting on-farm trials for technology verification must cope with potential sources of problems in the variation within and among farms in the target area, the diversity in the farmers' existing practices, and the diversity in the management practices required by the treatments to be tested.

Farms and Replications Within a Farm. In a technology verification study, variation occurs among farms and among plots, or fields, within the same farm. The inclusion of several test farms takes care of the first type of variation, and replication within a farm takes care of the second.

Between these two sources of variation, the first is expected to be larger, and a sufficiently large number of farms should be included relative to the number of replications within each farm. Whereas two replications used per farm is normally adequate, the number of test farms needed in a given case is not as easily specified, as it depends upon the magnitude of the variation among farms, the degree of precision desired, and the resources available.

The diversity of cropping pattern in the target area is a good index of variability among farms. A target area with many dominant cropping patterns is considered more variable and requires more test farms compared to one with fewer dominant cropping patterns. Generally, the average number of test farms for each type of farmer's cropping pattern should be about ten.

To ensure a proper representation of the farmers in the target area and a valid inference of the results obtained, the test farms should be selected at random, separately for each cropping pattern.

To each test farm, one of three possible sets of treatments is assigned, so that a set of complete factorial (or fractional factorial) is tested in $\underline{n}_3$ farms, a set of mini-factorial treatments in $\underline{n}_2$ farms, and a set of supplemental treatments in $\underline{n}_1$ farms such that:

$$n_1 + n_2 + n_3 = n$$

where $\underline{n}$ is the total number of test farms. Because the number of treatments in the supplemental set is the smallest followed by the mini-factorial set and so on, $\underline{n}_1$ is usually the largest followed by $\underline{n}_2$ and $\underline{n}_3$, respectively. The major factors affecting the choice of $\underline{n}_1$, $\underline{n}_2$, and $\underline{n}_3$ are the farm-to-farm variation, the importance of interaction effects among test factors, and the resources available. For the rice yield constraints study, for example, the minimum number of test farms per target area is set at 20 and the ratio of $\underline{n}_1 : \underline{n}_2 : \underline{n}_3$ used is 3:1:1 (IRRI 1979). A detailed description of the procedure for selecting the appropriate number of test farms and the allocation of the different sets of treatments to the test farm is given in Chapter 9.

Determination of the Farmer's Practice. Whereas the level of each test factor for the new technology can be clearly specified prior to the conduct of the verification trial, that for the farmer's practice is not known in advance and has to be determined for each test farm through actual observations of the farmer's operations throughout the cropping season. The use of an "average" or "representative" farmer's level, although simpler, is not desirable because the physical and the biological environment as well as the farmer's practice vary greatly among farms. Thus, the comparison between the new technology and the farmer's practice is valid only if it is done on a per farm basis.

An accurate determination of the farmer's level for all test factors is necessary in each farm where the set of complete factorial, fractional factorial, or mini-factorial treatments is tested. On these farms, experimental plots receive various combinations of intermediate technology in which some test factors are set at the farmer's level whereas others are at the high level of the new technology. However, an accurate simulation of the farmer's practice may not be necessary on farms where only the supplemental treatments are tested, because here only one plot having all the test factors at the high level needs to be established. The yield level of the farmers' practice is determined by a crop cut from an adjacent plot being cultivated by the farmer.

Considering that new technology usually requires a level of management higher than the farmer's practice, a very practical technique for implementing a technology verification trial is to allow the farmer to apply his practices over the whole experimental area and the researcher applies the additional practices and inputs required by the new technology on the specific plots that require it (Gomez 1977). The farmer's practice can, thus, be easily and accurately simulated.

Experimental Design and Plot Layout. With the many factors needing to be evaluated simultaneously in a technology verification trial, the treatments involved usually differ widely in the management practices required. Thus, when a complete factorial, a fractional factorial, or a mini-factorial trial is to be tested, the choice of a specific experimental design and plot layout to be used should be based on the following three considerations.

First, some test factors like insect control and land preparation need larger plots than, say, fertilization; and special plot arrangements may be needed for them. A split-plot design or a group balanced-block design (Gomez and Gomez 1976) is appropriate in such cases since it allows for a larger plot size to be used for one test factor relative to that for the others.

Second, when the farmer is the one establishing the farmer's level, the plot layout should not be an obstacle but should be made to facilitate his operations. Experience in lowland rice (Gomez et al. 1979), for example, indicated that a larger plot size than that normally required should be used in order to minimize the obstruction to the farmer's operation due to the presence of levees between plots. Also, a treatment allocation that allows plots receiving the same level of a test factor, say, insect control, to be placed together in contiguous area can facilitate the farmer's operation when he is the one to implement that test factor.

Third, if the whole experiment cannot be accommodated in one field, or paddy, all treatments of the same replication should be placed in the same field whereas different replications can be allocated to other fields.

Data Collection

Data collection in an on-farm technology verification experiment does not have to be as detailed as that normally performed in a research station trial, either in terms of the number of characters measured or in the measurement techniques employed. Only data that are essential for explaining the contributions -- individually or in combination -- of the test factors need be collected. For all practical purposes, only data on productivity from each and all experimental plots are needed. However, other data, such as that on pest and disease incidences or weeds, may be helpful in explaining the among-farm variation in the contributions to the yield gap of the test factors. However, detailed data on agronomic traits (such as plant height and tiller number at varying growth stages) or on yield components (such as grain weight or percentage of unfilled grain), which are commonly collected in research station trials, are generally not needed in an on-farm technology verification experiment.

In a supplemental trial, an area adjacent to the new-technology plot is demarcated to represent the farmer's level. In this area, data collection and other observations must be made throughout the crop season in the same manner as those in the new-technology plot. Also, information on the farmer's level of each of the test factors must be monitored.

On a farm where either the set of complete factorial, fractional factorial, or mini-factorial treatments is tested, a crop is cut for yield determination from an area adjacent to the experiment for comparison with the yield obtained from the plots simulated at farmer's level. This comparison measures the degree of accuracy with which the farmer's level has been simulated in the experimental plots.

Data Analysis

Two major types of data analyses performed in a technology verification experiment are the yield gap analysis, which measures the total yield gap and the relative contribution of each test factor to the yield gap, and a cost and return analysis, which measures the relative profitability of the new technology, the farmer's practice, and the intermediate technologies.

Yield Gap Analysis. The yield gap analysis determines the difference in biological yield between the farmer's practice and the new technology. It was originally developed for use in technology verification trials involving a single crop. However, when multiple cropping is involved, the yield gap analysis can be performed for each crop component that is common to both the new and the farmer's technology.

When the technology verification experiment involves the same cropping pattern, for example, rice - corn in both the new technology and the farmer's practice as described in Case I, the yield gap analysis is applied to each of the two crops independently. On the other hand, if the new technology involves a rice - rice cropping pattern and the farmer's cropping pattern is rice - corn (see Case II), then the yield gap analysis is applicable only to the rice crop that is common to both technologies. Clearly, the yield gap analysis is not applicable in cases where the cropping pattern for the new technology and for the farmer's practice has no crop in common.

The computational procedure is illustrated using the treatments described in Table 8.1.

Estimating the Yield Gap. The yield gap is computed, for each farm, as the difference between the yield of the new technology and that of the farmer's practice as follows:

$$G_i = Y_{fi} - Y_{hi} \qquad [8.1]$$

where G_i is the yield gap in the *i*th farm; Y_{fi}, the yield of the farmer's practice in the *i*th farm, and Y_{hi}, the yield of the new technology in the *i*th farm.

Because the new technology and the farmer's practice (treatments number 1 and 16 see Table 8.1) are tested in all test farms, estimates of the yield gap are available from all test farms regardless of the set of treatments being tested. The estimate of the yield gap for the target area, $\overline{G}$, is then computed as

$$\overline{G} = (1/n) \sum_{i=1}^{n} G_i \qquad [8.2]$$

where n is the total number of test farms.

Calculating the Contribution of each Test Factor. Except for farms with supplemental treatment, data from all other test farms can be used for calculating the contribution of each test factor.

Step 1 - Using data from complete factorial (or fractional factorial) trials, construct a combined analysis of variance over farms, following the format shown in Table 8.6, to provide a means for determining the presence of interaction effects among the test factors.

Step 2 - Perform one of the following two analyses depending upon the significance of the interaction effects among test factors as determined in step 1.

a) When interactions among test factors are significant, compute both the individual and joint contributions of test factors, separately for each farm, following the specific formulae prescribed for each type of trials in Table 8.7. Then, compute the average of the individual contributions over all farms testing the complete factorial treatments and the average of the joint contributions over all test farms except the supplemental farms. (Individual contributions are available only from the farms testing the complete factorial set of treatments. On the joint contributions, all are available from the complete factorial farms but only some are available from fractional factorial farms or from the mini-factorial farms. No contribution of test factors, individually or jointly, can be obtained from the supplemental farms.)

b) When interaction effects are not appreciable, compute the average contribution for each test factor, separately for each farm, following the specific formulae prescribed for each type of trial in Table 8.8. Then, compute the mean of the average contributions over all test farms to represent the average contributions of the individual test factors for the target area.

Cost-and-Return Analysis. The yield improvement of the new technology over the farmer's practice is usually accompanied by an increase in the cost of production due to the added requirement for materials and labour. Superiority of the new technology over that of the farmer's practice can not, therefore, be measured solely in terms of biological yield, but must also consider the cost of production and, ultimately, the net profit to the farmer. To do so, additional data on prices of the products and costs of inputs are needed for both the new technology and the farmer's practice. To obtain these additional data, the following guidelines can be used.

Table 8.6. Combined analysis of variance over farms for the complete factorial and the fractional factorial sets of treatments from Table 8.1

Source of variation	Degrees of freedom (d.f.)[1]	
	Complete factorial	Fractional factorial
Farms	f - 1	f - 1
Reps within farms	f (r - 1)	f (r - 1)
Treatments	15	7
F	(1)	(1)
V	(1)	(1)
W	(1)	(1)
I	(1)	(1)
F x V	(1)	(1)
F x W	(1)	(1)
F x I	(1)	(1)
V x W	(1)	-
V x I	(1)	-
W x I	(1)	-
F x V x W	(1)	-
F x V x I	(1)	-
F x W x I	(1)	-
V x W x I	(1)	-
F x V x W x I	(1)	-
Farm x treatment	15 (f-1)	f (f-1)
Pooled error	15 f (r-1)	7f (r-1)
Total	16fr - 1	8fr - 1

[1] f = no. of farms and r = no. of replications per farm.

a) Price determination. The specific time in which a certain crop is grown and harvested is an integral part of the cropping pattern being tested. Price of a product usually varies during the year, even within the same area. Thus, the prices used in the computation of profits for the different production technologies, especially when multiple cropping is involved, should be determined separately for each individual farm and at the specific time when harvesting was completed.

b) Cost determination. Costs should be determined for individual crops in each cropping pattern tested. For each crop that is not common to the new technology and the farmer's practice, the total cost of all operations involved (both materials and labour costs) must be

Table 8.7. Computational procedures for the individual and joint contributions of the test factors in a technology verification experiment, when interactions among test factors are present; based on treatments described in Table 8.1

Test factor	Estimate of contribution[1]		
	Complete factorial	Fractional factorial	Mini-factorial
	Individual contribution		
Fertilizer (F)	$Y_{15} - Y_{16}$	-	-
Variety (V)	$Y_{14} - Y_{16}$	-	-
Weed control (W)	$Y_{12} - Y_{16}$	-	-
Insect control (I)	$Y_8 - Y_{16}$	-	-
	Joint contribution		
F and V	$Y_{13} - Y_{16}$	$Y_{13} - Y_{16}$	-
F and W	$Y_{11} - Y_{16}$	$Y_{11} - Y_{16}$	-
F and I	$Y_7 - Y_{16}$	$Y_7 - Y_{16}$	-
V and W	$Y_{10} - Y_{16}$	$Y_{10} - Y_{16}$	-
V and I	$Y_6 - Y_{16}$	$Y_6 - Y_{16}$	-
W and I	$Y_4 - Y_{16}$	$Y_4 - Y_{16}$	-
F and V and W	$Y_9 - Y_{16}$	-	$Y_9 - Y_{16}$
F and V and I	$Y_5 - Y_{16}$	-	$Y_5 - Y_{16}$
F and W and I	$Y_3 - Y_{16}$	-	$Y_3 - Y_{16}$
V and W and I	$Y_2 - Y_{16}$	-	$Y_2 - Y_{16}$

[1] Y_i (i = 1, ..., 16) refers to the yield of the ith treatment as Indicated in Table 8.1.

assessed. On the other hand, for crops that are common to both the new technology and the farmer's practice, the only costs needed are those that are related to each and all test factors. Included in this category are the cost of the material and labour inputs required for the implementation of the test factors, and the harvesting and processing of the added output resulting from the use of the high levels of the test factors.

In computing the cost of labour, both family and hired labour should be costed, based on the prevailing wage rate, which could be either the average annual wage rate or the varying monthly mean wage rate for the target area. The latter is preferred in cases where the wage rate varies greatly over time. In terms of the material inputs, the direct cost of the input as well as the interest on this cost should be considered. Because the cost of material inputs and the interest rate do not usually vary appreciably over time, the average prices paid by farmers in the target area can be used.

Table 8.8. Computational procedures for the average contributions of the test factors in a technology verification experiment when interactions among test factors are not present; based on treatments described in Table 8.1

Test factor	Estimate of average contribution[1]		
	Complete factorial	Fractional factorial	Mini-factorial
Fertilizer (F)	$\frac{Y_1+Y_3+Y_5+Y_7+Y_9+Y_1+Y_{13}+Y_{15}}{8} - \frac{Y_2+Y_4+Y_6+Y_8+Y_{10}+Y_{12}+Y_{14}+Y_{16}}{8}$	$\frac{Y_1+Y_7+Y_{11}+Y_{13}}{4} - \frac{Y_4+Y_6+Y_{10}+Y_{16}}{4}$	$Y_1 - Y_2$
Variety (V)	$\frac{Y_1+Y_2+Y_5+Y_6+Y_9+Y_{10}+Y_{13}+Y_{14}}{8} - \frac{Y_3+Y_4+Y_7+Y_8+Y_{11}+Y_{12}+Y_{15}+Y_{16}}{8}$	$\frac{Y_1+Y_6+Y_{10}+Y_{13}}{4} - \frac{Y_4+Y_7+Y_{11}+Y_{16}}{4}$	$Y_1 - Y_3$
Weed control (W)	$\frac{Y_1+Y_2+Y_3+Y_4+Y_9+Y_{10}+Y_{11}+Y_{12}}{8} - \frac{Y_5+Y_6+Y_7+Y_8+Y_{13}+Y_{14}+Y_{15}+Y_{16}}{8}$	$\frac{Y_1+Y_4+Y_{10}+Y_{11}}{4} - \frac{Y_6+Y_7+Y_{13}+Y_{16}}{4}$	$Y_1 - Y_5$
Insect control (I)	$\frac{Y_1+Y_2+Y_3+Y_4+Y_5+Y_6+Y_7+Y_8}{8} - \frac{Y_9+Y_{10}+Y_{11}+Y_{12}+Y_{13}+Y_{14}+Y_{15}+Y_{16}}{8}$	$\frac{Y_1+Y_4+Y_6+Y_7}{4} - \frac{Y_{10}+Y_{11}+Y_{13}+Y_{16}}{4}$	$Y_1 - Y_9$

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[1] Y_i (i = 1, .., 16) refers to the ith treatment as indicated in Table 8.1.

For the cost-and-return analysis, all biological products including the factors of production are converted into a common monetary unit. Consequently, the difficulty of combining biological yield from different crops, as encountered in the yield gap analysis, does not hold. Thus, in the cost-and-return analysis, the new technology, the farmer's practice, and all intermediate technologies are directly comparable not only on a per crop basis, but more importantly, on the basis of the whole cropping pattern. The step-by-step procedures for the cost-and-return analysis are described.

Step 1 - Computation of the value of output.

In each farm and for each treatment (i.e., package of technology) tested, compute the value of output as follows:

$$V = \sum_{i=1}^{c} PiYr \qquad [8.3]$$

where Y_i is the yield of the ith crop, p_i is the price of the ith crop, and c is the total number of crops in the cropping pattern tested. A computation of the value of output is illustrated in Table 8.9.

Step 2 - Computation of the total cost.

In each farm and for each treatment tested, production cost is first determined separately for each crop and the total cost is the sum of the costs over all crops in the cropping pattern. Costing must be made for all operations involved in the production of every crop not common to both the new technology and the farmer's practice. For each of the crops that is common to both, compute its cost as follows:

$$C = C_p + \sum_{i=1}^{k} C_i \qquad [8.4]$$

where C_p is the cost of harvesting and processing, C_i is the cost of the ith test factor, and k is the total number of test factors. A partial budgeting approach is used here, in which only the costs associated with the test factors and with harvesting and processing are included in the analysis. For the new technology, all C_i's are based on the high level; for the farmer's practice, all C_i's are based on the farmer's level; and for the rest of the treatments, there are some of each.

The total cost for each treatment is then the sum of the computed costs for all the crops in the cropping pattern tested, as illustrated in Table 8.10. In this case, the partial budgeting approach is applied to the first rice crop which is common to both the new technology and the farmer's. For the second crop, either rice or corn, the total budgeting approach is applied (i.e., costing is made for all operations involved).

Step 3 - Computation of the added return over the farmer's practice and the benefit-cost ratio for each treatment or package of technology.

Table 8.9. Computation of value of output for five mini-factorial treatments tested in a technology verification experiment involving a rice - rice cropping pattern as the new technology against a rice - corn cropping pattern of the farmer

Treatment					Yield			Yield x Price[3] ($/ha)			
	1st rice crop[2]					2nd crop			2nd crop		
No.[1]	M	F	L	2nd crop	1st crop (t/ha)	Rice (t/ha)	Corn (kg/ha)	1st rice crop	Rice	Corn	Value of output ($/ha)
1	h	h	h	rice	5.0	5.0	na	850	950	na	1800
2	f	h	h	corn	4.6	na	3.1	782	na	527	1309
3	h	f	h	rice	4.0	4.8	na	680	912	na	1592
5	h	h	f	rice	4.8	4.9	na	816	931	na	1747
8	f	f	f	corn	3.5	na	3.0	595	na	510	1105

[1] Corresponds to the treatment number of Table 8.5.

[2] M = method of planting, F = fertilizer, and I = insect control.

[3] Price of first rice crop is $0.17 per kg; price of second crop is $0.19 per kg.; and price of corn is $0.17 per kg.

Table 8.10. Computation of the total cost for the rice - rice (new technology) and the rice - corn (farmer's practice) cropping patterns of Table 8.5

Crop	Test factor	Input	Cost ($/ha)	
			Farmer's practice	New technology
First[1]	Method of planting	Land preparation	53.40	66.75
		Seedling establishment	46.43	34.63
		Herbicide	0.0	24.10
		Hand-weeding	15.96	37.24
		Total	(115.79)	(162.72)
	Fertilizer	Fertilizer	56.65	101.97
		Labour	6.40	5.32
		Total	(63.05)	(107.29)
	Insect control	Insecticide	12.53	50.66
		Labour	2.66	5.32
		Total	(15.19)	(55.98)
	-	Harvesting/Processing	98.00	140.00
	TOTAL	-	(292.03)	(465.99)
Second[2]	-	Materials and labour for all operations	304.00	444.20
TOTAL COST			596.03	910.19

[1] Direct-seeded rice for new technology and transplanted rice for farmer's practice.
[2] Rice for new technology and corn for farmer's practice.

In each farm and for each treatment:

a) Compute added return (AR) over the farmer's practice as

$$AR_a = R_a - R_f \qquad [8.5]$$

where subscript a refers to treatment a, subscript f refers to the farmer's practice, and R is the return above cost calculated from

$$R = V - T \qquad [8.6]$$

where V is the value of output and T, the total cost.

b) Compute the benefit-cost ratio (BC) as

$$BC = AV/AC \qquad [8.7]$$

where AV is the added value of output over the farmer's practice computed as

$$AV_a = V_a - V_f \qquad [8.8]$$

and AC is the added cost over the farmer's practice computed as

$$AC_a = T_a - T_f. \qquad [8.9]$$

Results of such computations are shown in Table 8.11. In terms of added return and benefit-cost ratio, the new technology is clearly superior to the farmer's existing practice. However, treatment 5, an intermediate technology consisting of an improvement in the farmer's method of planting and fertilization, has a higher benefit-cost ratio and only a marginally lower added return compared to the new technology. Thus, treatment 5 should be seriously considered as a substitute to the new technology, i.e., instead of recommending the adoption of all three component technologies, insect control could be dropped and only the method of planting and higher fertilization be recommended.

Step 4 - Computation of the added return over the farmer's practice and the benefit-cost ratio for each test factor.

When there is no interaction among test factors, the economic benefit due to the application of the high level for each test factor can be computed in farms that tested either the complete factorial, the fractional factorial, or the mini-factorial set of treatments. The procedure for each is as follows:

a) Compute the added value of output contributed by the ith test factor (AV_i) as

$$AV_i = V_h - V_b \qquad [8.10]$$

where V_h is the value of output of the new technology and V_b is the value of output of the particular treatment in which the ith test factor is at the farmer's level. For example, using the data of Table 8.9, the added value of output due to the

Table 8.11. Summary of the cost-and-return analysis of the existing farmer's practice (rice - corn), the new technology (rice - rice) and three intermediate technologies

Item[1]	Farmer's practice	Intermediate technologies[2]			New technology
		Treatment 5	Treatment 3	Treatment 2	
Value of output[3]	1105.00	1747.00	1592.00	1309.00	1800.00
Total cost[4]	596.03	861.00	831.63	714.66	910.19
Return above cost	508.97	886.00	760.37	594.34	889.81
Added return over farmer's practice	-	377.03	251.40	85.37	380.84
Added value of output over farmer's practice	-	642.00	487.00	204.00	695.00
Added cost over farmer's practice	-	267.97	235.60	118.63	314.16
Benefit-cost ratio	-	2.43	2.07	2.39	2.21

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[1] Except for benefit-cost ratio, the unit for all other items is $/ha.

[2] See Table 8.9 for treatment description.

[3] Taken from Table 8.9.

[4] That for farmer's practice and new technology were taken directly from Table 8.10. The derivation of the values for the intermediate technologies is illustrated for treatment 5 as follows: 861 - 162 + 107.29 + 15.19 + (140.00 - 5.6) + (444.20 - 2.8).

Derived from Tables 8.9 and 8.10.

Table 8.12. Computation of the contribution of each test factor to the difference in economic benefits between the new technology and the farmer's practice

Item[1]	Method of planting	Fertilizer	Insect control
Added value of output	491.00	208.00	53.00
Added cost	198.33	72.24	46.39
Added return	292.67	135.76	6.61
Benefit-cost ratio	2.48	2.88	1.14

[1] Except for benefit-cost ratio, the unit for all other items is \$/ha. Derived from Tables 8.9 and 8.10.

method of planting is computed as the difference between the value of output of treatment 1 and the value of output of treatment 2; i.e., $V_1 - V_2 = 1800 - 1309 = 491$ \$/ha. The added value of output for each of the other two test factors can be computed in a similar manner. Results for the three test factors are shown in the first row of Table 8.12.

b) Compute the added cost contributed by the *i*th test factor as the sum of three components:
   (i) the difference between the cost of the *i*th test factor under the high level and that under the farmer's level;
   (ii) the increase in the harvesting/processing cost caused by the increased production contributed by the *i*th test factor and
   (iii) the difference between the cost of producing the succeeding crop(s) in the new technology and that in the treatment in which the *i*th test factor is at the farmer's level.

For example, using the data of Table 8.9 and 8.10, the added costs for the three test factors are computed as follows, and are shown in the second row of Table 8.12.

For method of planting, the three components of the added cost are:

$$162.72 - 115.79 = 46.93,$$

$$\frac{(140.00 - 98.00)\,(5.0 - 4.6)}{(5.0 - 3.5)} = 11.2, \text{ and}$$

$$444.20 - 304.00 = 140.20.$$

The added cost due to the method of planting is therefore,

$$46.93 + 11.2 + 140.20 = 198.33.$$

For fertilizer, the three components of the added cost are:

$$107.29 - 63.05 = 44.24,$$

$$\frac{(140.00 - 98.00)\ (5.0 - 4.0)}{(5.0 - 3.5)} = 28.00, \text{ and}$$

zero (since the second crop is the same).

The added cost due to fertilizer is, therefore,

$$44.24 + 28.00 = 72.24.$$

For insect control, the three components of the added cost are:

$$55.98 - 15.19 = 40.79,$$

$$\frac{(140.00 - 98.00)\ (5.0 - 4.8)}{(5.0 - 3.5)} = 5.6, \text{ and}$$

zero (since the second crop is the same).

The added cost due to insect control is, therefore,

$$40.79 + 5.6 = 46.39.$$

c) Compute the added return contributed by the ith test factor as the difference between the added value of output and the added costs. Results for the three test factors are shown in the third row of Table 8.12.

d) Compute the benefit-cost ratio of the ith test factor as the ratio between the added value of output and the added cost. Results for the three test factors are shown in the last row of Table 8.12.

Clearly, improved fertilization is the best investment followed closely by method of planting, whereas insect control showed the lowest benefit-cost ratio. These results substantiate the findings from step 3 where the intermediate technology involving only the combination of method of planting and fertilizer gave a higher benefit-cost ratio than the whole package of the new technology involving all three test factors.

With the quantification of the contribution of each test factor both in yield gap analysis and in cost-and-return analysis, the productivity and economic benefit of all intermediate technologies can be estimated, including those that were not actually tested. For example, although a treatment that has fertilizer at the high level and both method of planting and insect control at the farmer's level was not tested in the mini-factorial farms, the productivity and economic benefit of such a treatment can be estimated. From Table 8.9, the productivity of the first rice crop with such a treatment would be estimated at

$$Y_f + D_F = 3.5 + 1.0 = 4.5 \text{ t/ha}$$

where Y_f is the yield under farmer's practice and D_F is the individual contribution of fertilizer to the yield gap.

The computation of the contribution of each test factor is valid only when the test factors do not interact with each other. Interaction amongst factors should, whenever possible, be evaluated using data from complete or fractional factorial trials. If these types of trials are not available, however, the mini-factorial trials can be used to indicate the presence or absence of large interactions. This is done by comparing the total yield gap to the sum of the contributions of individual test factors as defined under Yield Gap Analysis. If these two figures are the same or very close to each other, the interaction is judged to be absent or negligible. For example, in Table 8.9, the total yield gap in the first crop is 1.5 t/ha whereas the contributions of the test factors are 0.4 t/ha for method of planting, 1.0 t/ha for fertilizer, and 0.2 t/ha for insect control. The sum of these three contributions is 1.6 t/ha, which is very close to the total yield gap.

When the interaction amongst factors is judged to be small, the computation of the economic benefit due to each test factor is considered valid. If, on the other hand, the interaction among test factors is large and significant, the economic benefit computed for each treatment tested should be used instead and the evaluation of intermediate technologies should be confined to only those that were actually tested in the field experiments.

Step 5 - For each parameter computed for each test farm as outlined in steps 1 to 4, compute the average over all test farms that provide data for its computation.

Combined Experiments for Technology Generation and Technology Verification

With the usual urgency for the development of production technologies that are superior to existing ones, the design and subsequent verification of suitable cropping patterns for a given area are usually initiated even if the information on some of the technology components is incomplete. In such cases, it may be advantageous to design an experiment that combines both features of technology generation and technology verification. That is, in addition to comparing the new package of technology with that of the farmer's, several levels of one or more components of technology are tested simultaneously.

The method used is a combination between that for an on-farm technology generation experiment and that for a technology verification experiment. Only the methodological features pertaining specifically to the combining process are discussed here.

Selection of Test Farms. The procedures for selecting farms where experiments are to be located should follow that for technology verification. Test farms should be selected at random in the target area, rather than purposely chosen to represent some specific environmental conditions as is done for an on-farm technology generation experiment.

Experimental Design and Layout. The choice of the specific combinations of the different sets of treatments to be tested in the different farms should follow that for technology verification. That is n_1 farms are assigned with the supplemental treatments, n_2 farms with the mini-factorial treatments, and n_3 farms with the complete factorial treatments (or fractional factorial treatments). In all farms, except those with supplemental treatments, exactly the same procedure as that used in the purely technology verification experiment is followed. It is only in the supplemental farms that the technology generation part is implemented. Thus, in each farm receiving the supplemental treatments, the varying levels of the component technology to be evaluated are superimposed on the new-technology plot to form the technology generation part of the experiment, i.e., a section of the plot is divided into t small plots, each receiving at random one of the t levels of the component to be tested (Zandstra et al. 1978). Because the treatments are superimposed on the new-technology plot, all the other test factors

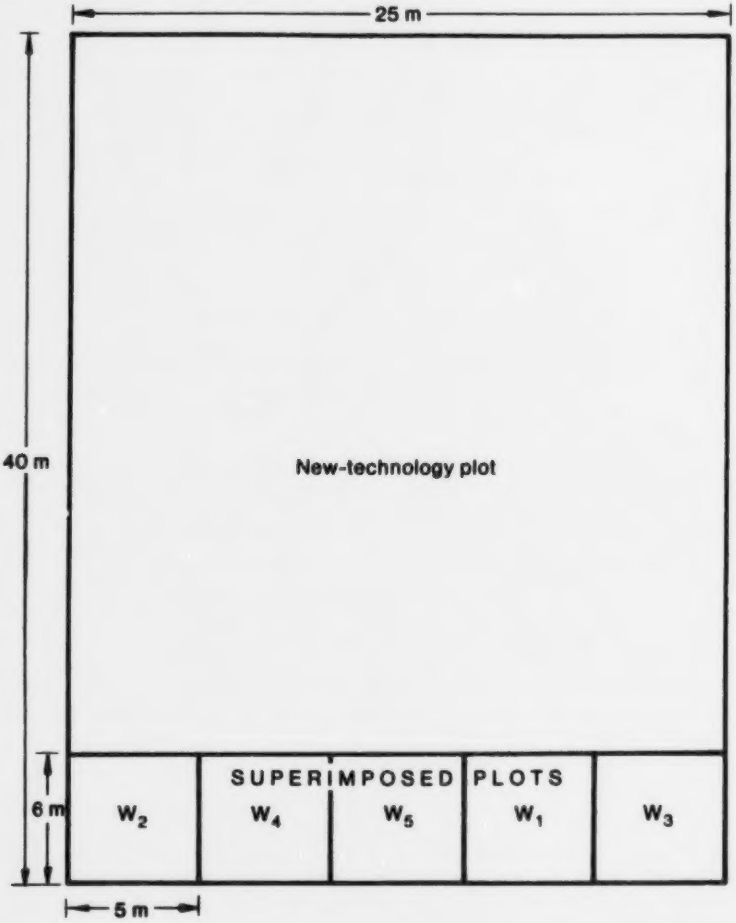

Figure 8.2. A sample layout with five weed-control treatments superimposed in a supplemental trial as a part of a combined experiment for technology generation and verification.

under evaluation in the technology verification part are at the high level prescribed by the new technology. In the sample layout of a superimposed trial (Figure 8.2), note that the sixth weed control method, represented by the high level of the new technology is already embedded in the new technology package applied to the rest of the plot and, hence, does not require an additional superimposed plot.

Farmer's Participation. In the supplemental farms, farmer's participation in the management of the plot representing the new technology should still be used whenever it is deemed necessary for the verification process. On the other hand, those operations related to the component technology being tested in the superimposed plots (e.g., the weed control methods in Figure 8.2) should be done solely by the researcher.

Data Collection. In the supplemental farms, all data needed in the usual technology verification experiment are to be collected in the area of the new-technology plot, that is outside the superimposed plots. On the superimposed plots, more-detailed data concerning crop performance and the environmental conditions related to the component technology being tested (such as weed incidence in the case of testing weed control methods) should be collected in the same manner as that normally done in an on-farm technology generation trial. Also, an area in the new-technology plot of the size of a superimposed plot immediately adjacent to the superimposed plots should be demarcated to represent the high level of the test component technology which was not tested in any of the superimposed plots. In this area, data collection should be the same as that in a superimposed plot.

CHAPTER 9: FARM SURVEY FOR TECHNOLOGY VERIFICATION

The environmental factors that influence the suitability of a production technology to a given location can be classified into two groups: biophysical factors such as rainfall, soil characteristics, and pest incidence; and socioeconomic factors such as the availability of labour and capital, the status of input and output markets, and existing rural institutions. The biophysical factors are usually evaluated by researchers conducting the on-farm trials through actual observations and measurements. On the other hand, information on the socioeconomic factors is usually obtained from farmers' responses to questions posed to them by researchers in a farm survey.

The farm survey complements well the on-farm trials for technology verification for the following reasons:

a) Many socioeconomic factors do not lend themselves easily to actual physical measurement. The farmer himself must volunteer information on income, education, household labour, assets, and liabilities, for example.

b) A farm survey can be conducted in less time and with less cost than field experiments, and a larger number of farms can thus be included. It provides an effective means of widening the scope of coverage of technology verification.

c) Whereas information gathered through field experiments is limited to the current phenomena, the farm survey can cover information from the past and, to some extent, that about the future. Past information usually provides a good basis for selecting suitable new technology to be verified.

Technology verification usually includes the joint application of the field experiments discussed in Chapter 8, and the farm survey.

The Pre-Design Survey

In the process of technology verification, a pre-design survey is conducted prior to the establishment of the field experiments, to gather information on the existing farmers' practices, their production, and the major constraints to increased productivity. Such information is needed not only for the design of the new technology to be compared to the farmer's existing practice, but also for the selection of the test farms on which to conduct of field experiments.

Survey Procedure

Compared to the usual socioeconomic surveys that are concerned with a wide array of rural development indices, the pre-design survey is more specific in its objective and focus, and is mainly concerned with the farm enterprise, its management, and its productivity. Its concern with the farm household is limited primarily to features closely associated with the operation of the farm enterprise. Thus, the questionnaire for a pre-design survey is more compact than those used in the usual socioeconomic surveys.

Because the pre-design survey aims to provide information needed for the design of new technology as well as for the selection of the test farms where field experiments are to be conducted, its procedure must incorporate two important requirements. First, the survey questionnaire should focus on the factors responsible for the low farm productivity -- the same factors that might be further evaluated in the field experiments. Secondly, the number of sample farms must be large enough to provide an adequate selection of the test farms.

Questionnaire. Constraints to production vary with the farmer's existing technology and the environment of the target area. Consequently, the type of information that should be gathered in a pre-design survey will vary among target areas. However, some common guidelines to follow in the design of the questionnaire are:

a) Use short questionnaire. There are three important advantages of a short questionnaire. First, because the farmer's attention diminishes with the length of the interview, information gathered from a short questionnaire is expected to be more accurate than from a long one. Secondly, it allows for smaller cost and wider coverage. Thirdly, faster and easier data summarization allows needed information to be made available in time for the planning and establishment of the field experiments.

   There are two useful techniques for shortening the questionnaire in a pre-design survey. First, avoid the temptation for combining or merging the pre-design survey with other surveys. The technology verification process is usually undertaken as part of a rural development program in which a benchmark survey, designed to evaluate in detail the status of the rural community prior to the initiation of the development program, is needed. In such cases, there is a tendency to combine the pre-design survey with the benchmark survey, in that it would save time and resources because the farmer respondents need to be visited by an enumerator only once. Experience, however, indicates that the resources saved do not compensate for reduced accuracy due to a lengthy questionnaire and for the additional analysis required by a more voluminous data set.

   Secondly, limit the coverage of certain information to only the more important cropping patterns. Data become lengthy and monotonous if repeated for several patterns in the same farm. To avoid this problem, the usual procedure is simply to record, for each farm, the three most dominant cropping patterns and their area and to obtain details on the productivity and management practices of only the single most dominant cropping pattern.

b) Use simple questions. Farm surveys are effective in gathering information only when questions can be easily and accurately answered by farmers: for example, those on current crops, existing farm equipment, and farm household. Other information, however, may not be so accurately obtained for any of the following reasons.

First, farmers can not easily recall specific information: for example, details of farm activities are not easy for farmers to remember, because they usually perform several in the same day and may have performed these several weeks or months before. Secondly, farmers are hesitant to disclose information about the farm or household which they consider private. Household income is a typical example. Thirdly, farmers may not know the correct information. Some farm characteristics are not uniform throughout the farm, and it may not be easy for them to arrive at the correct answer.

Experience indicates that the seriousness with which farmers regard a survey questionnaire diminishes with the difficulty of the questions he has to answer. To avoid including difficult questions in a questionnaire, the following guidelines may be useful. First, whenever possible, supplement the interview with other sources of information. For example, information on the man-hour requirement to perform a specific operation, say, plowing, may not be easy to obtain through the questionnaire. If a reliable estimate of the labour requirement for plowing, under varying conditions, is available from past studies in the target area; all that need to be asked of the farmer in the pre-design survey would be the size of the farm, the equipment used for plowing, and the number of times the farm was plowed -- all of which are easier for the farmers to recall. Secondly, use indirect questioning for sensitive issues like income, about which farmers are generally hesitant to answer. Alternatively ask several less-sensitive questions, from which to arrive at the required information. For example, farm income can be computed from information on crop yields, the manner with which these products were disposed, and the off-farm employment of household members.

The type of information asked in a pre-design survey is summarized in Table 9.1. This questionnaire, developed following the guidelines mentioned, consists of a minimum of 78 questions and is considered to be both short and simple. The average time required for the actual interview using this questionnaire is 30 minutes per farmer.

Sample Size. With the usually large number of farmers within a target area, only a small sample can be included in the farm survey. The sample size, for the pre-design survey for technology verification must be large enough not only to give the required precision in estimating some farm characteristics that are considered important to the aims of the survey, but also to provide enough sample farms from which to select those that will be used as test farms. Given a desired degree of precision, the determination of sample size for a pre-design survey is dependent upon the magnitude of variability in the levels of productivity among farms, on one hand, and the resources available on another.

For the purpose of technology verification of multiple-cropping technologies, the more cropping patterns there are, the greater is the variability in farm productivity, and subsequently the larger is the sample size required.

For each existing cropping pattern, an average of ten test farms should be allotted for verification trials. Because the predesign survey provides a sampling frame upon which selection of test farms for verification trials is based, the number of sample farms in

Table 9.1. The farm features included and the corresponding type of questions asked in a pre-design survey for technology verification conducted in Urdaneta, Pangasinan, Philippines, in 1978

Farm features	Information asked	No. of questions
Household members	Age, occupation, educational attainment	3
Whole farm	Area, number of parcels	2
Largest farm parcel	Area, soil texture and fertility, slope, irrigation, distance from road, cropping patterns	9
Most important cropping pattern:		
Management practices for each crop	Crop, variety, planting area, date planted and harvested, tillage, planting method, fertilization, insect control, weed control, rodent control, adequacy of input, pest and other problems	39
Credit	Amount borrowed, source, terms, adequacy	6
Production	Total, operator's share, labour's share, amount sold, price	5
Expenses	Farm and non-farm	11
Others	Power source, farmer's willingness to cooperate in the field trial	3

Source: Multiple Cropping Section, Department of Agronomy, UPLB.

the pre-design survey should be at least four times the number of test farms.

Based upon these considerations, sample size for a pre-design survey can be determined in two ways depending on the availability of prior information on cropping patterns in the target area.

a) *With prior information on the cropping patterns.* If the number of cropping patterns, p, in the target area is not more than five and if none covers an area less than 10% of the target area, the sample size should be at least 40 p. If p is larger than five such that the sample size of 40 p is too large for the available resources, only the dominant cropping patterns (i.e., where the combined hectarage covers at least 50% of the target area) may be considered. In this case, sample size is 40 p', where p' is the number of dominant cropping patterns.

b) *Without prior information on the cropping patterns.* The initial sample size should be set at about 200 farms. Experience in the Philippines indicates that most characteristics of interest in a pre-design survey can be estimated with reasonable degrees of precision with sample size of 200 farms (Table 9.2). Using a questionnaire of a reasonable length, the interview of 200 farms can be completed within a reasonably short time. For the survey in Urdaneta (see Table 9.1), for example, five interviewers completed the survey of 200 farms in only one week.

From the results of the initial survey of 200 farms, if the number of cropping patterns is more than five, one of the following steps can be taken depending upon the resources available: either take m additional farms where m = 40, p = - 200, and p = number of cropping patterns identified from the initial survey; or take m' additional farms where m' = 40, p' = - 200, and p' = number of dominant cropping patterns.

Use of Survey Results

The results from the pre-design survey are used both in the design of a new production technology that is to be compared with the farmer's existing practice, and in the selection of test farms to be used for field experiments. For the design of the new technology, information is necessary on the existing farm environment, management practices, and the crop yield, whereas the selection of the test farms requires knowledge of the diversity in cropping patterns currently used by farmers.

Design of the New Technology. A major task in the technology verification process is to test designs of production technologies expected to be superior to farmers' existing practices. The pre-design survey contributes to this design phase by describing the farmer's existing practice and identifying which components of this practice are likely to constrain farm productivity. Improved practices are then substituted for these identified production constraints resulting in a newly designed package of technology that combines the desirable features of both the existing practices and the promising technologies derived from experiments.

Table 9.2. Mean and among-farm variability for some selected farm characteristics, from pre-design surveys in nine provinces of the Philippines in 1980[1]

Province	Area		Parcels		Household members		Cropping pattern		Productivity	
	Mean (ha)	CV (%)	Mean (No.)	CV (%)	Mean (No.)	CV (%)	Mean (No. crops)	CV (%)	Mean ($/ha)	CV (%)
North Cotabato	1.97	6.3	1.58	4.7	5.44	3.8	1.18	2.6	491.49	5.0
South Cotabato	2.83	9.7	1.42	3.3	6.64	3.0	1.71	2.3	798.96	4.6
Davao	2.28	5.4	1.56	3.9	6.76	2.8	1.94	1.6	702.86	7.4
Ilocos Norte	1.46	7.3	3.49	4.1	6.66	2.5	2.08	2.3	2754.64	11.6
Iloilo	1.54	4.8	1.29	3.3	6.30	2.9	1.99	1.7	704.10	4.8
Leyte	1.00	8.1	1.94	4.4	5.66	3.6	1.96	2.6	715.29	9.0
Mindoro	2.54	5.9	1.66	4.2	5.95	2.8	1.92	1.2	598.92	6.2
Northern Samar	2.71	5.8	1.54	4.7	6.20	2.8	1.25	2.6	434.65	5.8
Pangasinan	1.53	4.4	2.34	4.2	6.48	2.6	2.04	2.0	863.07	4.5

[1] Based on a sample size of 200.

Source: Multiple Cropping Section, Department of Agronomy, UPLB.

Results from the technology verification work conducted in Urdaneta, Philippines illustrate the design process, through step-by-step procedures.

Step 1 - Identify the more commonly used cropping patterns in the target area. In Urdaneta, the five lowland rice-based cropping patterns, identified in Table 9.3, occupied 78.7% of the area.

Step 2 - Describe the biophysical environment of the target area relevant to the major cropping patterns identified. For lowland rice-based cropping patterns, the two most important determinants are water availability and soil texture (see Chapter 2). Based on the 18-year record of the nearest meteorological station, Urdaneta receives an average of 1816 mm rainfall per year, most of which fall from May to October (Figure 9.1). Soil texture is primarily sandy loam.

Step 3 - Decide whether simply to improve the component technology of the existing cropping patterns or to introduce entirely new cropping patterns. This depends primarily on the length of the growing season or the number of days in a year when available water exceeds that normally required by the crop. If none of the existing cropping patterns uses more than 80% of the available growing season, then the introduction of a new cropping pattern can be seriously considered. Otherwise, the new technology should consist mainly of improved component technology in one or more of the existing cropping patterns. In the case of Urdaneta, for example, the rainfall data suggests adequate water to support a sequence of two crops. Because the existing cropping patterns there already include a sequence of two and even three crops, the main target of the design of the new technology should be to improve the existing component technology of the most dominant cropping pattern in the area, namely, the rice - mung-bean cropping pattern.

Table 9.3. Hectarage and yield of the five major cropping patterns obtained from a pre-design survey in Urdaneta, Pangasinan, Philippines, in 1978

Cropping pattern	Hectarage (%)	Yield (t/ha)	
		1st rice crop	Other crops
Rice - mung beans	30.9	3.404	0.324
Rice - rice	17.0	3.392	2.789
Rice	15.1	3.435	-
Rice - mung beans - corn	9.7	3.852	0.752[1]
Rice - tomatoes	6.0	3.726	2.021

[1] Combined yield of mung beans (0.316) and corn (0.436).

Source: Multiple Cropping Section, Department of Agronomy, UPLB.

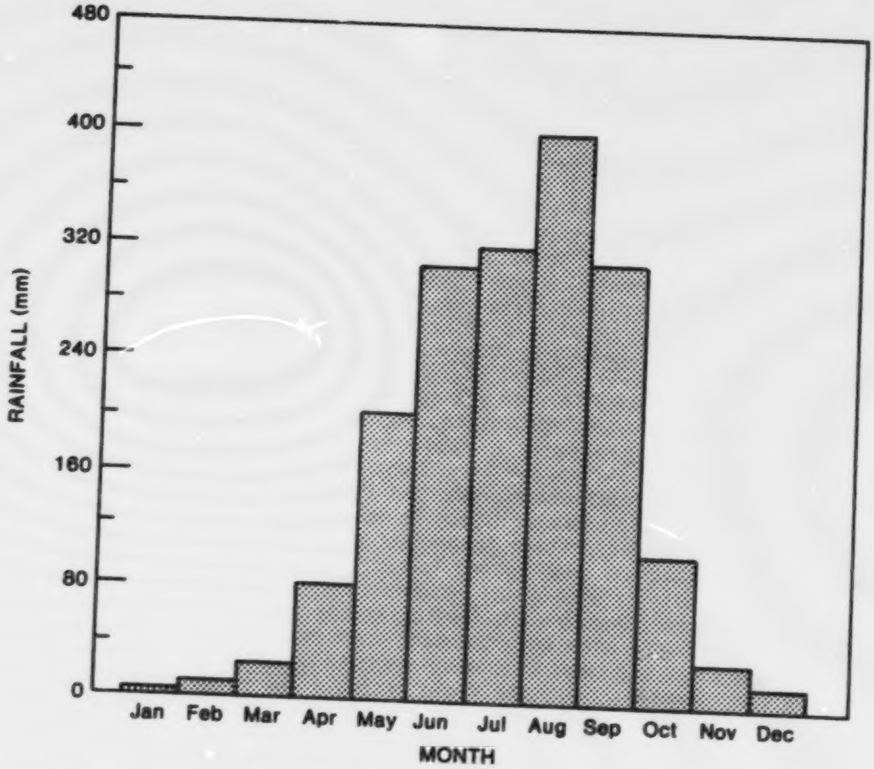

Figure 9.1. An 18-year average monthly rainfall distribution for Pangasinan, Philippines.

Step 4 - Prescribe the component technology for the cropping pattern chosen in step 3. If the cropping pattern to be tested is an existing one, first identify those of its management components suspected of constraining the productivity. The choice can be made based on the examination of the farmers' management and cultural practices and the cost associated with each major operation.

For the example at Urdaneta, seven component technologies in the rice - mung-bean cropping pattern -- three for the rice crop and four for the mung-bean crop -- were identified as possible constraints to high productivity. These were fertilization, and insect and weed control of rice crop, for which, based on the average costs per hectare (Table 9.4), the existing practices are all considered to be inadequate; and variety, land preparation, fertilization, and insect control of the mung-bean crop. Only 22% of the farmers used improved mung-bean varieties, and no fertilization and minimal chemical insect control were practiced by the farmers in the target area (Table 9.4). On land preparation, experimental evidence exists that minimum tillage after rice is superior to the existing practice of full tillage.

Table 9.4. Description of some farmer's component technologies in the rice - mung-bean pattern obtained from a pre-design survey in Urdaneta, Pangasinan, Philippines in 1978

Component technology	Rice	Mung beans
Land preparation/tillage	puddling	dryland tillage
Variety	improved	local (78%)
Fertilization[1]	56.03	0.00
Insect control[1]	6.35	10.17
Weed control[1]	7.59	0.98

[1] The data given are costs of chemicals in $/ha.
Source: Multiple Cropping Section, Department of Agronomy, UPLB.

After identification, the new technology for each of the test factors should be prescribed. The new package of technology for the rice - mung-bean pattern to be tested in Urdaneta is shown in Table 9.5.

Step 5 - Examine the economic feasibility of the newly designed package of technology. The two important indices of economic feasibility for each of the test factors are the added cost and the break-even yield increase (i.e., the yield increase the value of which is equal to the added cost). These two indices for the seven test factors in the rice - mung-bean cropping pattern are given in Table 9.6. Results indicate sufficiently favourable economic feasibility for all the seven test factors. Thus, the package of technology (see Table 9.5) is considered appropriate for use in the verification process in Urdaneta.

Selection of the Test Farms. The number of test farms should be large enough to attain the desired level of precision in the test results but should also be within the resources available. For a given degree of precision, the larger the variability in productivity among farms, the more test farms are needed. In the context of multiple cropping, variability in farm productivity is closely related to the variability in cropping patterns. Thus, for simplicity, the number of test farms to be used for field experiments in each target area should be closely related to the number of important cropping patterns obtained from the results of the pre-design survey. The step-by-step procedures for the determination of the number of test farms are listed.

Step 1 - Identify the dominant cropping patterns in the target area from the results of the pre-design survey. A cropping pattern is said to be dominant if it is included in a set of the most commonly used cropping patterns the joint hectarage of which exceeds 50% of the target area. In Urdaneta, the three dominant cropping patterns are rice - mung beans, rice - rice, and monocrop rice which have a joint hectarage of 78.7% of the total.

Step 2 - Set the initial number of test farms, n, at 10 p, where p is the number of dominant cropping patterns. Therefore, for Urdaneta with three dominant cropping patterns, the initial number of test farms should be 30.

Step 3 - Adjust the total number of test farms derived from step 2 to fit the available resources by including or excluding one or more cropping patterns from the set of dominant cropping patterns. That is, if the available resources allow for more test farms than that prescribed in step 2, the next most commonly used cropping pattern is added to the set, and the number of test farms is correspondingly increased. If, on the other hand, available resources are not enough to accommodate the number of test farms as specified in step 2, the dominant cropping pattern with the lowest hectarage could be dropped from the set and the number of test farms is correspondingly reduced. For example, in Urdaneta, if available resources could support field tests in 40 farms, then the rice - mung beans - corn pattern could be added to the list of cropping patterns that would be compared to the new technology in the verification trials. If, on the other hand, only 20 test farms could be implemented, then the rice - mung-bean pattern to be tested in Urdaneta is shown in Table 9.5.

The deletion or addition of one or more cropping pattern to be tested is of major significance to the generalization of results. By reducing the number of cropping patterns to be tested, the coverage of the target area is correspondingly reduced and, consequently, the number of potential farmer beneficiaries is also reduced.

Table 9.5. Seven component technologies of the new production package involving the rice - mung-bean cropping pattern designed for technology verification in Urdaneta, Pangasinan, Philippines in 1978

Component technology	Rice	Mung beans
Variety	Farmer's level	CES 55
Fertilizer (N-P-K in kg/ha)	90-30-30	45-45-45
Insect control	Furadan + Brodan (2x) + Gusathion (2x)	Fungitox (2x)
Weed control	Hand-weeding (4x)[1]	Farmer's level
Planting method	Farmer's level	zero tillage and seeds dibbled

[1] From planting up to 40 days after transplanting.
Source: Multiple Cropping Section, Department of Agronomy, UPLB.

Table 9.6. Economic feasibility of each of the seven component technologies incorporated in the rice - mung-bean cropping pattern for technology verification trials in Urdaneta, Pangasinan, Philippines in 1978

Component technology[1]	Added cost ($/ha)	Break-even yield increase (t/ha)
	Rice crop	
Fertilizer	26.63	0.16
Insect control	22.98	0.14
Weed control	5.74	0.03
	Mung-bean crop	
Variety	10.50	0.01
Fertilizer	64.00	0.06
Insect control	15.50	0.02
Planting method	0.00	0.00

[1] Described in Table 9.5.

Step 4 - To each cropping pattern identified in step 3 for inclusion in the verification trials, allocate the number of test farms proportionately to the area of coverage, provided that the number of test farms allotted to any one cropping pattern is not less than six. For example, in Urdaneta, where three dominant cropping patterns are to be tested, the proportional allocation of the 30 test farms is 14 farms for rice - mung beans, 9 farms for rice - rice, and 7 farms for rice monocrop.

Step 5 - Identify the specific farms to be used for conducting the field experiments, first by grouping the sample farms used in the predesign survey on the basis of the existing cropping pattern employed; and secondly, by selecting, at random, the corresponding number of test farms as determined in step 4 from each group of farms corresponding to each of the cropping patterns identified in step 3.

The Follow-up Survey

On the premise that farmers will adopt only those component technologies more productive than their existing practice, the follow-up survey is designed to determine the socioeconomic and institutional constraints that could prevent farmers from replacing their existing practices by the new and more-productive technology. Thus, the follow-up survey is conducted either towards the end, or after completion, of the verification trials when the specific components of the new technology that are more productive than the farmers' practices have already been identified.

Survey Procedure

The sample farms to be included in the follow-up survey consist of those that participated in the field experiments and those that did not. Because farmers who participated in the field experiments have a special advantage in that they are familiar with the new technology, all of these farms should be included in the follow-up survey. Those that did not participate should be selected from those used in the pre-design survey. Depending upon the availability of resources, the number of sample farms that did not participate in the field experiments should be at least the same as, or up to twice, those that did. Thus, the total sample size for the follow-up survey is two to three times that used in the field experiments.

With its specific and narrow focus on a few selected component technologies, the questionnaire for the follow-up survey concentrates on two types of information: first, the requirements of the new technology that can be satisfied or that are available on the farm; and secondly, the institutions that can provide the requirements that are not available on the farm.

In contrast to the pre-design survey in which a common set of questions is asked to all sample farms, that for the follow-up survey is expected to differ among farms in the target area. This is so because the sample farms differ in terms of their existing cropping patterns, the specific factors constraining their productivity, and their exposures to the new technology. Thus, the type of questions to be asked of each farmer depends upon the following considerations.

a) Participation in the field experiment. Farmers who participated in field experiments are expected to be familiar with the new technology and, therefore, should be asked questions concerning their views or opinions on the feasibility of the new technology. On the other hand, farmers who did not participate in the field experiments may, or may not, know about the new technology and, therefore, can not be expected to evaluate intelligently the new technology.

b) Existing cropping pattern. When the cropping pattern used by the farmer is the same as that in the new technology, the focus of the follow-up survey is on the component technology in each crop. No questions concerning newly introduced crops need to be asked since no new cropping pattern was tested.

c) Questions included in the pre-design survey. Questions already included in the pre-design survey need not be included in the follow-up survey since they have already been asked to all the sample farmers.

Given below are examples of questions that could be included in the questionnaire, for each component technology (e.g., improved fertilizer, improved insect control, or a new crop in the cropping pattern) that has been identified through field experiments to be more productive than the farmer's practice.

On requirements of the new technology that are available in the farm:

1. Do you think the new technology is profitable enough to be adopted in your farm? (Note: For farmers who did not participate in the field experiments, detailed description of the new technology and the input requirements should first be provided.) Would you adopt it in the next cropping season or cropping year? If so, in what portion of your farm? If not, why not?

2. Do you have the equipment (specific equipment required by the component technology should be named) required by the new technology? If not, can you have the use of one when needed? If so, how and from where?

3. If you were to adopt a technology that requires X dollars and Y man-days per hectare (the actual figures of X and Y must be specified for each component technology, based on the results of the field trial), how much of these cash and labour inputs can you provide from your existing farm resources? From what other possible sources can these inputs be obtained?

4. Because the new technology involves a new crop (name the crop), how would you use or dispose of the products of the new crop? How much can your family consume? Can you easily sell the excess product? If so, how and where? (Note that these questions are needed only if the new technology includes one or more new crop.)

On institutions that can provide the needed requirements:

5. Who do you consult for problems on your farm? (List in order of importance: neighbours, community leaders, government technicians, commercial dealers, etc.) How often do you change your management practices? What are the usual reasons for these changes?

6. Have you ever used credit? If so, how often? What are your sources of credit? What are the terms? Are they easy to secure?

7. Where do you buy your chemical inputs? Can you get them anytime you want them? If not, why not?

8. Are there other institutions that can help you in your farm enterprise? What are they, what do they do, and how often do you use them?

Data Analysis

The follow-up survey is designed primarily to identify the important constraints to the adoption by farmers of production technologies for which productivity has been shown by field experiments to be superior to that used at present by farmers. The focus of the survey is on the requirements of the new technology that farmers may find difficult to satisfy. Consequently, the emphasis in analysing data in the follow-up survey is to match the requirement of the new technology with the existing farm resources, to identify specific constraints to its adoption. A common procedure for data analysis and data summarization is first to identify the probable constraints to adoption for each component technology and to determine the frequency of farmers that are subjected to each of these constraints. This is illustrated with a hypothetical case in which the new technology of a rice - mung-bean cropping pattern (as described in Table 9.5) is compared to each of the two existing cropping patterns, rice - mung beans and rice monocrop. in this example, it is assumed that there are 60 sample farms in the follow-up survey, 20 of which are farms where field experiments were conducted. The results (Table 9.7) show that more than half of the farmers who participated in the field experiments indicated that they will adopt the new technology and that the two primary constraints to

Table 9.7. A summary of the results of a hypothetical follow-up survey in technology verification[1]

Item	Fertilization of rice	Insect control of mung beans	Additional crop
Additional input cost ($/ha)	60	45	190
Cost - benefit ratio	1:2.2	1:2.0	1:2.5
Number of sample farms	60	40	20
Major constraints (%[2])			
Lack of cash	15	8	5
Risky or not profitable	25	15	25
No equipment	-	5	10
Material inputs not available	-	-	15
Institutions required for adoption (%)[2]			
Credit	60	60	20
Private dealers	100	100	100
Technicians	10	30	40
Market for produce	-	-	20
Farmers who will adopt (%)	50	40	80

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[1] Comparing the new technology involving a rice - mung-bean cropping pattern as described in Table 9.5 with two farmers' existing practices; rice - mung beans and rice monocrop.

[2] % of farmers indicating so.

adoption are the higher risk and the lack of cash in the implementation of the new technology.

The following points are illustrated by the example shown in Table 9.7. First, not all component technologies tested in the field experiments are included in the follow-up survey. Only those shown by the field experiments to be more productive than the corresponding farmer's practice are considered. Secondly, only farmers whose existing technology is the same as that tested in the field experiments are included as sample farms in the follow-up survey. For example, in this case, only farmers whose cropping patterns are rice - mung beans or rice monocrop are included. Lastly, analysis on the potential and major constraints to adoption by farmers is done separately for each component technology.

The Informal Survey

Both the pre-design and follow-up surveys as described in this chapter are formal surveys involving the use of standard sets of questions to be answered by the farmer respondents. Although their preparation requires the expertise of well-trained and experienced people, the actual interviewing process is not difficult. Experience in the Philippines indicates that high-school graduates can be successfully trained to become good interviewers. That such standardized formal surveys have only meager demands for highly skilled manpower is a major advantage and a feature that is very important in developing countries where well-trained and experienced personnel are scarce.

However, a standardized formal survey may not be capable of capturing some special features of the farms in the target area that could be an important consideration in the conduct of technology verification. Also, the raw data from the formal survey have to undergo rigorous analysis and proper interpretation and presentation of results before they can be of use in the verification process. In most instances, such analyses are so time-consuming that the survey information may not be made available at the time when it is most needed, e.g., the pre-design survey may not be analyzed early enough for use in selecting the test farms for the field experiments.

A promising alternative to the formal survey is the informal survey done by a team of experts who visit the target area, observe the existing physical environment and the farmers' practices, and conduct informal interviews with some selected members of the rural community (farmers, dealers of agricultural chemicals, and community leaders).

The team of experts is composed of experienced researchers from different specializations. Each member conducts his own informal survey focusing on his specialization, and, through a series of frequent meetings with other team members, a comprehensive description of the target area is completed during the period of the survey.

A good example of the informal survey is the Sondeo of Instituto de Ciencia y Technologia Agricolas (ICTA) in Guatemala (Hildebrand 1979). The Sondeo is designed to identify the major farming systems in a target area, to discover common agro-socioeconomic problems and constraints facing farmers in the area, and to provide the initial basis for designing the new technology (Hildebrand 1979). A team consisting of five social scientists and five biological scientists of various disciplines, works in a target area for 6 to 10 days. The specific activities involved in the Sondeo are the unstructured interviewing of members of the community by pairs of team members (each pair composed of one social and one biological scientist); discussions among members of the whole team in between each set of interviews; and the preparation of a single team report.

The Sondeo has three major advantages. First, it provides an opportunity for each team member to be acquainted not only with farmers but also with other team members. Each team member has the opportunity to interact and be acquainted with the activities of the others even though they represent different disciplines. Secondly, the time lag between the actual survey and the summary of results is very short. The major emphasis is given to group interaction and no effort is made to collect and analyze "hard data". However, nearly all critical information necessary for the design and testing of new technologies can be obtained by the Sondeo (Hildebrand 1979). However, the personnel requirement of the Sondeo is rather substantial. Ten highly trained and experienced specialists must spend one to two weeks of full-time work in each target area. This adds up to a substantial personnel resource if many target areas are to be worked on, simultaneously. Thus, the informal survey is applicable only in situations where the interdisciplinary team of experts can be easily formed from the existing pool of experienced researchers, a requirement that is very difficult to satisfy in many developing countries of the humid tropics.

CHAPTER 10: VARIETAL IMPROVEMENT FOR MULTIPLE CROPPING

Performance of a genotype in a given environment, is usually termed the phenotype, and expressed by the equation

$$Y_{ij} = U + G_i + E_j + (GE)_{ij} \qquad [10.1]$$

where Y_{ij} is the phenotypic value of the ith genotype grown in the jth environment, U is the population mean of phenotypic values, G_i is the effect of the ith genotype, E_j is the effect of the jth environment, and $(GE)_{ij}$ is the effect of the interaction between the ith genotype and the jth environment.

For a given set of environments and genotypes, U is constant and the variability among phenotypes is explained by the effects of the genotype, the environment, and the interaction between them. Thus, the development of an improved technology is based on the identification of a particular combination of environment and genotype that maximizes Y_{ij} or, equivalently, maximizes the sum of G_i, E_j, and $(GE)_{ij}$. An improvement of the environment (E_j) is generally accomplished with the use of good management practices (i.e., appropriate fertilization, pest control, and water management) whereas an improvement of the genotype, G_i, and the interaction between genotype and environment, $(GE)_{ij}$, can be accomplished through the use of crop species or varieties of a species that can best exploit the resources of the uncontrollable factors of the environment.

There are two categories of activities involved in the identification of the best genotype for a specific environment in multiple cropping. These are cropping-pattern testing, in which the best crop species are selected, and varietal improvement in which the best varieties within a species are developed. Methods for cropping-pattern testing were discussed in Chapters 7 and 8, and methods for varietal improvement in multiple cropping are discussed here.

Approaches to Varietal Improvement for Multiple Cropping

There are two alternative approaches in designing a varietal improvement program for multiple cropping. First, if different varieties are expected to perform equally well over a wide range of environments, then the best genotypes selected under monocropping conditions are also best for multiple cropping. Based on this assumption, the traditional breeding program, in which the best genotypes are selected only under the favourable environmental condition of monocrop and with the best management practices, could serve just as well the requirements of multiple cropping. Secondly, if the different genotypes are expected to differ greatly in their efficiency to use the varying levels of environmental resources, the best genotypes under the optimum environment of monocropping may not be those that will best suit the more limiting environments of multiple cropping. Based on this second assumption, the traditional breeding program cannot be expected to produce varieties that will best suit the multiple-cropping environments.

What is required, therefore, is a multi-environment selection strategy in which varietal selection is conducted separately for different environments. Under this strategy, varietal selection is conducted for each specific multiple-cropping environment in which the varieties are to be applied, to identify those varieties uniquely suited to that particular environment.

There are two major considerations in deciding which of the approaches should be followed in a given situation.

a) Magnitude of the interaction between genotype and environment. The larger the interaction between genotype and environment, the larger is the advantage of performing varietal selection in several environments. Multiple cropping magnifies the diversity in environment under which a crop is grown (see Chapter 6). Consequently, the interaction between genotype and environment is generally expected to be high when multiple cropping is involved.

b) Cost of varietal selection. A good varietal improvement program must evaluate as many genotypes as possible. Under the traditional method of selection involving only a single environment, this evaluation process is already expensive. The addition of more environments will greatly increase the resources required. With the usually meager manpower and financial resources for research in developing countries, it is essential that these resources be efficiently used. Whereas the selection of desirable varieties in several environments is a good way to cope with the presence of the interaction between genotype and environment, it is also expensive; and, if the interaction is small, it could be unnecessarily wasteful. Thus, the multi-environment selection strategy should be adopted only when it is necessary, e.g., when the best varieties selected in one environment are not expected to excel in another environment.

Estimation of the Interaction Between Genotype and Environment

The primary basis for determining a suitable breeding approach to adopt is the expected magnitude of the interaction between genotype and environment. It indicates whether the traditional breeding program can also serve the requirements of multiple cropping, and, if not, how the procedure should be modified to satisfy the needs of multiple cropping. Hence, an accurate estimate of the interaction between genotype and environment is needed to choose the most suitable approach to varietal improvement.

For estimating the magnitude of the interaction between

Table 10.1. Simple correlation coefficients between the yields of some annual upland crops grown under monocrop and those grown under multiple cropping environments, obtained from published reports[1]

Crop[2]	No. of trials	Varieties (av. no./trial)	Correlation coefficient (*r*)		Trials with significant[3] *r* (%)
			Av.	Range	
			Monocrop vs intercrop		
Cereals	11	28	0.59	0.35 to 0.90	73
Legumes	14	19	0.59	-0.36 to 0.91	71
Sweet potatoes	4	12	0.50	0.14 to 0.87	50
			Monocrop vs after-rice crop		
Cereals	8	14	0.24	-0.10 to 0.82	50
Legumes	7	14	0.48	-0.11 to 0.94	29
Sweet potatoes	2	10	0.81	0.75 to 0.87	100

[1] Sources: Buajarem (1978); Lantican (1977); CIAT (1978); Francis et al. (1978a, 1978b, 1978c, 1979); ICRISAT (1977); IRRI (1976, 1977); UPLB (1975; 1977b, 1978); and VSIC (1976, 1977).

[2] Cereals include corn, sorghum, and pearl millet; legumes include beans, mung beans, soybeans, and cowpeas.

[3] At 5% level of significance.

genotype and environment, several statistical procedures are available. Three of these are the correlation technique, the combined analysis of variance technique, and the regression technique.

Correlation Technique

The simple linear correlation coefficient (*r*) measures the degree of association between two variables based on the amount of variability in one character that can be explained by a linear function of the other (Gomez and Gomez 1976). The value of the correlation coefficient ranges from -1 to +1, with the two extreme values indicating perfect association and a value of zero indicating absence of a linear relationship.

When several genotypes are tested in several environments, a simple linear correlation coefficient between the performance of the genotypes in any two environments provides a measure of the magnitude of the interaction between genotype and environment. A large and positive *r*-value (close to +1) indicates that the relative performance of the genotype in one environment is similar to that in another; which indicates a small interaction between genotype and environment or no interaction at all. An *r*-value of zero, or close to zero, indicates a lack of association between the performance of genotypes in one environment and that in another, such that the varietal performance observed in one environment is not useful in predicting its performance in another. A large and negative *r*-value (close to -1) indicates that the best variety in one environment would be the worst in the other; which is indicative of a very large interaction between genotype and environment. Thus, *r*-value is a good index of the interaction between genotype and environment, i.e., the larger the *r*-value the smaller is the interaction.

The correlation method is not only simple but its data requirement is also easy to satisfy: replicated data are not required and the average is sufficient. Thus, the correlation technique is a convenient tool for estimating the magnitude of the interaction from published reports. The use of such data not only provides a rapid and inexpensive means of obtaining the needed information (without the need to conduct the costly and time-consuming experiments) but also offers wider coverage.

As an illustration, data from 15 published reports involving a few selected species of annual crops were used to determine simple correlation coefficients, based on crop yield, between monocrop and intercrop and between monocrop and after-rice crop. Results are summarized in Table 10.1. Most of the correlation coefficients were positive and, in the rare instances when its numerical value was negative, none was judged to be significant. For the cereals and legumes, the average correlation coefficients between monocrop and intercrop were considerably higher than those between monocrop and after-rice crop. Moreover, there were more significant correlation coefficients between monocrop and intercrop than between monocrop and after-rice crop. These results indicate that, for cereals and legumes, there is more urgency to evaluate and select varieties separately for the environment of the after-rice crop relative to the intercrop environment. For sweet potatoes, on the other hand, the average correlation coefficient as well as the frequency of significant correlations were considerably higher for the case between monocrop and after-rice crop than between monocrop and intercrop. Hence, for sweet potatoes, selections made under the monocrop environment could probably be safely used for the after-rice crop environment whereas separate selections should be considered for the intercrop environment.

Combined Analysis of Variance Technique

The analysis of variance, a commonly used tool in analyzing experimental data, is a procedure for subdividing the total variation of a set of data into several identifiable components. When replicated variety trials are conducted over several environments, the combined analysis of variance is able to separate out that portion of the total variation due to the genotypes from that due to the environments and from that due to the interaction between genotype and environment (Kempthorne 1952; Cochran and Cox 1957; Sutjihno and Gomez 1968; Steel and Torrie 1980). Also, the level of significance for each of the three components can be tested and their relative sizes compared. The relative sizes of these three components of variation provide an indication of whether the interaction between genotype and environment is large enough to warrant a shift from the traditional single-environment selection strategy to the multi-environment strategy.

As an illustration, combined analyses of variance of varietal trials in sorghum, mung beans, and soybeans, each conducted under three to five different test environments, are taken from various published reports and summarized in Table 10.2. The F-test is used to indicate significance of environment, genotype, and the interaction between genotype and environment. Significant interaction was observed in all cases except for sorghum. In the case of sorghum, the interaction component contributed a negligible fraction of the total variation of less than 1% (Table 10.3). Between mung beans and soybeans, the contri-

Table 10.2. Combined analyses of variance taken from published reports[1] involving sorghum, mung bean, and soybean varietal trials tested under varying environments[2]

	Source of variation				
Crop	Environment	Reps. within environment	Genotype	Genotype x Environment	Pooled error
Sorghum					
d.f.	2	5	15	30	75
MS	87.231	0.866	1.752	0.350	0.331
F	100.7**	-	5.3**	1.1ns	
Mung beans					
d.f.	3	4	19	57	76
MS	5.282	0.037	0.035	0.048	0.025
F	142.8**	-	1.4ns	1.9*	
Soybeans (1977)					
d.f.	3	4	15	45	60
MS	5.111	0.233	0.160	0.109	0.034
F	21.9**	-	4.7**	3.2**	
Soybeans (1978)					
d.f.	4	10	23	92	230
MS	20.657	0.066	0.280	0.110	0.011
F	313.0**	-	25.5**	10.0**	

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[1] UPLB (1977a) for sorghum; Lantican (1977) for mung beans and soybeans (1977); and Buajarem (1978) for soybeans (1978).

[2] Test environments: Monocrop, intercrop, and after-rice for sorghum; monocrop, intercrop, after-rice (mulched), and after-rice (unmulched) for mung beans and soybeans (1977); and monocrop (dry season), monocrop (wet season), intercrop (dry season), intercrop (wet season), and after-rice for soybeans (1978).

Table 10.3. Estimates of variance components ($\underline{s}'$) and the relative contribution of the genotype, the environment, and their interaction to the total variance of yield data in varietal trials of selected annual upland crops[1]

Crop	Components of variance		
	Environment	Genotype	Interaction
Sorghum			
s^2	1.8659	0.1818	0.0073
% of total	90.8	8.8	0.4
Mung beans			
s^2	0.1311	0.0016	0.0115
% of total	90.9	1.1	8.0
Soybeans (1977)			
s^2	0.1525	0.0064	0.0378
% of total	77.5	3.3	19.2
Soybeans (1978)			
s^2	0.2860	0.0113	0.0330
% of total	86.6	3.4	10.0

[1] Estimated from data of Table 10.2.

bution from the interaction seemed to be higher for the latter. In the case of mung beans, the variation due to genotype was extremely small and not significant. In all cases, the largest contributor to the total variation is environment.

Where significant interactions between genotype and environment were observed and where there were more than two environments involved, the interaction sum of squares could be partitioned into two parts: genotype x (monocrop vs multiple cropping); and genotype x (among multiple-cropping environment).

The partitioning procedure was applied to the interaction sums of squares for the cases of mung beans and soybeans (see Table 10.2) and the results are presented in Table 10.4. In all cases, the part of the interaction that differentiates monocropping from multiple cropping, i.e., genotype x (monocrop vs multiple cropping), is highly significant, indicating that the interaction between genotype and environment is primarily due to the inconsistencies in the performance of genotypes tested under monocropping and multiple-cropping environments. For these crops, therefore, a multi-environment selection strategy needs to be considered.

Among the multiple-cropping environments, on the other hand, results differed between mung beans and soybeans. Only in mung beans was the interaction between genotype and three multiple-cropping environments -- intercrop, after-rice (mulched), and after-rice (unmulched) -- not significant. Thus, for mung beans, only one of the

Table 10.4. Partitioning of the variation due to the interaction between genotype and environment based on the monocropping and multiple-cropping environments[1]

Crop	Source of variation	
	Genotype x environment	
	Genotype x (monocrop vs multiple cropping)	Genotype x (among multiple-cropping environment)
Mung beans		
d.f.	19	38
MS	0.069	0.037
F	2.8**	1.5ns
Soybeans (1977)		
d.f.	15	30
MS	0.098	0.115
F	2.9**	3.4**
Soybeans (1978)		
d.f.	23	46
MS	0.152	0.028
F	13.8*	2.6**

[1] Data are from Table 10.2.

multiple-cropping environments needs to be included in the multi-environment selection strategy whereas more multiple-cropping environments may be needed for soybeans.

Regression Technique

The regression technique involves the computation of the stability index for each genotype over the different test environments and the comparison of these indices over genotypes. The stability index for each genotype is a simple linear regression coefficient between the performance of the genotype and the environmental index; the latter is represented by the mean performance over all genotypes at each environment or its deviation from the grand mean (Yates and Cochran 1938; Finlay and Wilkinson 1963; Eberhart and Russell 1966).

Unlike the combined analysis of variance technique, the regression technique does not require the availability of raw, or replicated data. It can be applied to data from published reports in the same manner as the correlation technique. However, unlike the other two techniques where the minimum number of test environments required is two, the regression technique requires a minimum of four.

As an illustration, yield data of 24 soybean varieties were evaluated under five environments -- dry season monocrop, dry season intercrop, after-rice wet season monocrop, and wet season intercrop

Table 10.5. Average yield and stability index for 24 soybean varieties grown under five environments

Variety	Yield (t/ha) Wet season monocrop	Dry season monocrop	After-rice	Wet season intercrop	Dry season intercrop	Av.	Stability index[1]
Multivar 80	2.567	1.943	1.132	0.962	0.897	1.500	1.35a
CES 31-1	2.302	1.860	1.093	0.729	0.703	1.337	1.33a
Cobb	2.588	1.470	1.052	1.179	0.660	1.390	1.25a
UPL-SY 2	2.600	2.075	1.289	1.244	1.095	1.661	1.20a
Bethel	2.105	1.732	1.124	0.803	0.538	1.260	1.20a
Williams	2.488	1.987	1.119	1.209	0.988	1.558	1.19ab
Kaoshiung # 3	2.375	2.023	1.385	1.181	0.905	1.574	1.13ab
TGM 225-3	2.175	1.617	0.978	0.873	0.710	1.271	1.13ab
Woodworth	2.367	1.017	1.067	0.823	0.633	1.181	1.09abc
Tainung # 4	2.370	1.828	1.345	1.103	0.965	1.522	1.07abc
TGM 84	2.045	1.668	0.778	0.986	0.707	1.237	1.07abc
Clark 63	2.277	1.897	1.230	1.202	0.898	1.500	1.05abc
EG-SY 78	2.038	1.692	1.057	0.856	0.808	1.290	1.02abc
Columbus	2.325	1.698	1.197	1.159	0.951	1.466	1.01abc
CES 30-2	2.332	1.607	1.319	1.084	0.977	1.464	0.97abc
K.E. 32	2.065	1.747	1.287	0.966	0.917	1.396	0.93bc
Imp. Pelican	1.907	1.508	1.056	0.960	0.695	1.225	0.89bc
S.J.1	1.825	1.602	1.008	0.814	0.768	1.204	0.89bc
T.K. 5	1.772	1.793	0.958	0.903	0.893	1.264	0.85bcd
Hill	1.695	1.472	1.235	0.879	0.688	1.194	0.74cd
Lincoln	1.512	1.710	1.289	0.717	0.742	1.194	0.72cd
L 114	1.625	1.607	1.342	0.775	0.910	1.252	0.66cd
No. 29	1.415	1.805	0.952	0.834	1.160	1.233	0.53cd
Wayne	1.422	1.713	1.299	1.032	1.033	1.298	0.43d
Mean	2.091	1.749	1.150	0.974	0.839	1.361	-
Environmental index	0.730	0.388	-0.210	-0.386	-0.522	0.000	-
C. V. (%)	6.39	3.15	13.73	7.36	5.13	-	-
H.S.D. (0.05)	0.413	0.171	0.489	0.222	0.133	-	-

[1] Indices followed by a common letter are not significantly different at 5% level.

Source: Buajarem (1978).

(Buajarem 1978). The results (Table 10.5) indicate the following three main points.

First, stability indices of all varieties are significant indicating their validity and meaningfulness. The variety Wayne (index low value) is more stable than variety Multivar 80 (index high value), with the former having a very narrow yield range of 1.032 to 1.713 t/ha and the latter having a much wider yield range of 0.897 to 2.567 t/ha.

Second, significant differences among the stability indices indicate the presence of an interaction among variety and environment. Although the tendency for each and all varieties is to have higher yields in the test environments with higher environmental indices, the varietal ranking differed greatly from one environment to another. For example, Multivar 80 gave a much higher yield than Wayne (2.567 vs 1.422 t/ha) under wet season monocrop, the environment with the highest environmental index; but gave a lower yield than Wayne (0.897 vs 1.033 t/ha) under dry season intercrop, the environment with the lowest environmental index. In such a case, a selection strategy that involves a single environment (i.e., only under the traditional monocropping condition) would have eliminated variety Wayne in spite of its potential for high yield under intercropping.

Third, the regression technique, aside from indicating the presence or absence of the interaction between genotype and environment, allows for the identification of specific varieties having high degrees of yield stability which is a desirable trait when multiple cropping is involved. Stable varieties are considered to be less risky since their yields are not expected to be very low even if the growing environment turns out to be unfavourable. Multiple-cropping environments are less predictable and, thus, are subjected more to unexpected occurrences -- either favourable or unfavourable. On the other hand, stability has been reported to be negatively correlated with the yield level (Cabangbang and Gomez 1972). That stable varieties tend not to give very high yields, even under very favourable environment, is confirmed by the present data where the correlation coefficient between the stability indices and the mean yields (see Table 10.5) is 0.51 which is significant at the 5% level of significance. However, with this relatively small, although significant, correlation coefficient, several exceptions to the trend can be expected. For example, varieties Columbus and K.E. 32 are two varieties with good performance under the most productive environment of wet season monocrop but also with comparable, if not better, yields than the more stable variety Wayne under the less favourable environments.

Strategies for Varietal Improvement for Multiple Cropping

The selection process in a varietal improvement program can be viewed as a series of chronological stages of evaluations, to which the many breeding lines are subjected, so that the most productive genotypes can ultimately be identified. When the interaction between genotype and environment is absent, the evaluation needs to be made in only one environment for all stages. However, with a large interaction between genotype and environment, it becomes necessary to evaluate the breeding lines not only in one, but in several, environments. The specification of the particular stage of evaluation in which multi-environment selection should be introduced is a major feature in the development of the strategy.

The selection process in a breeding program can be divided chronologically into the following stages:

Stage 1- Hybridization, when the parents to be used for crossing are selected;

Stage 2- Early segretating generation, when breeding lines are visually evaluated;

Stage 3- Preliminary yield test, when a rough estimate of the relative yields is obtained for the first time;

Stage 4- Advanced yield test, when a more precise yield estimate of the lines selected from the preliminary yield test is obtained from a replicated yield trial; and

Stage 5- Regional yield test, when a few outstanding lines are tested in several locations.

Although the above classification is based mainly on self-pollinated crops in which the end products of the breeding program are pure lines, equivalent steps can easily be identified for other programs. For example, for breeding programs designed to produce high-yielding F_1 hybrids, the main modification is an interchange of stages 1 and 2 to allow for inbreeding before hybridization. For programs designed to produce open-pollinated varieties, some types of family selection are substituted for the selfing process in stage 2.

Multi-environment selection may be introduced into the program at any one of the five chronological stages mentioned. In this way, if multi-environment selection is introduced in stage 1, different hybrids may be produced for different environments. Likewise, if multi-environment selection is introduced in stage 2, the early-generation lines are grown and judged visually in several environments. Also if multi-environment selection is introduced in stages 3, 4, or 5, respectively, the preliminary yield test, the advanced test, or the regional yield test is conducted in several environments. However, an introduction of the multi-environment selection at a particular stage necessitates multi-environment selections in all succeeding stages. Thus, if the preliminary yield test is conducted in two environments monocrop and intercrop, then both the advanced yield test and the regional yield test must necessarily be conducted under these two environments. This is so because the preliminary yield test, the initial stage in which the multi-environment selection is introduced, will produce two separate groups of selected genotypes -- one for each environment -- each of which needs to go through the succeeding stages separately. Thus, the earlier the multi-environment selection is introduced in the process, the larger is the amount of material to be handled and the greater are the resources required.

Although the multi-environment selection entails additional work and expense, identification of varieties best suited to a particular environment improves. Clearly, if the added advantage from the multi-environment selection is small (i.e., small yield advantage of varieties selected under intercropping over those selected under monocropping when grown under intercrop environment), then the use of the more costly multi-environment selection would be inefficient.

Using a computer simulation technique, Flores (1981) evaluated the progress in selection for two strategies, i.e., single-environment (monocropping) and multi-environment (monocropping, after-rice, and intercropping), and under two levels of interaction between genotype and environment. At the high level, the best genotype varies from one environment to another, and at the low level, the relative performance among genotypes varies among environments but the best genotypes remain the same. He concluded that the multi-environment selection strategy is not necessary under the low level of interaction, but is essential under the high level of interaction, because, in the latter case, the genotypes selected under monocropping do not perform as well as those selected under multiple-cropping environments, when grown under

Table 10.6. Mean yield and estimates of variance components due to genotype for sorghum, soybeans, and mung beans, separately for each environment tested[1]

Crop/Environment	Mean yield (t/ha)	Variance component due to genotype
Sorghum		
Monocrop	5.079	.3192
Intercrop	2.706	.0084
After-rice	2.644	.1282
Mung beans		
Monocrop	1.150	.0185
Intercrop	0.368	.0022
After-rice	0.981	.0028
Soybeans (1977)		
Monocrop	1.020	.0356
Intercrop	0.714	.0279
After-rice	1.609	.0322
Soybeans (1978)		
Monocrop	1.749	.0481
Intercrop	0.839	.0245
After-rice	1.150	.0159

[1] Source of data: see Table 10.2.

multiple-cropping environments. These results suggest that the use of the high-cost multi-environment selection strategy is justified only when the interaction between genotype and environment is sufficiently large to have caused major changes in the ranking among genotypes from one environment to another.

Based on the chronological stages in the selection process, the selection strategy should follow one of two courses.

First, when the interaction between genotype and environment is low, selection in stages 1 to 3 should be done in a single environment, and multi-environment selection should be introduced in stage 4. The single environment to be used in steps 1 to 3 should be one that produces the largest genotypic variation and the highest mean yield level as well as being one that covers the largest area with regard to the crop concerned. Because the genotypic variation is usually high under favourable environments and a crop is usually planted in environments where high yields can be expected, it is not difficult to find a single environment that possesses the three criteria thus prescribed. The monocrop environment is generally the strongest candidate for this purpose, because it generally has the highest productivity level and produces the largest genotypic variation (Table 10.6).

Second, when the interaction between genotype and environment is high, multi-environment selection should be introduced in stage 1. The type of environment that should be used in a single-environment selection, as described, should be included as one of the environments in the multi-environment selection. Other environments can then be chosen from those contributing to the very large interactions detected. For example, in the case of sweet potatoes (see Table 10.1), if selection is to be done in only two environments, the second environment to be used would be the intercrop environment instead of the after-rice crop, because the correlation between monocrop and intercrop is lower than that between monocrop and after-rice crop.

CHAPTER 11: RESEARCH STRATEGY

A research strategy is an allocation of resources into specific activities such that the objectives of the research are accomplished most efficiently. For any programs, especially those for which the coverage is as broad as multiple cropping, the development of a research strategy becomes very useful since it provides a clear perception not only of the research objectives but also of the specific activities that contribute towards their accomplishment.

By virtue of its dependence on existing information (i.e., the present state of knowledge), a research strategy is expected to be appropriate only for a limited time and is likely to change as some activities are completed or as significant discoveries are made. This chapter illustrates the process of developing a research strategy and the usefulness of, and consequently the need for, its consistent updating.

Defining the Efficiency Measure of a Research Strategy

If the aim of multiple-cropping research is to increase farm productivity, the efficiency of a research strategy can be measured as the change in farm productivity per unit cost, where cost is determined based on the most-limiting research resource.

Although there are several alternative measures of productivity, for the purpose of the present discussion, productivity is defined simply as the yearly output of the physical product (i.e., crop yield) per unit area of cultivated land. Thus, the expected change in farm productivity (ΔP) attributed to a new technology can be defined as:

$$\Delta P = Y_n - Y_f \qquad [11.1]$$

where $\underline{Y}_n$ is yield (t/ha) of the new technology, and $\underline{Y}_f$ is yield (t/ha) of the farmer's current practice.

The three resources which limit multiple-cropping research are manpower, money, and time, all of which are closely related. Thus, for simplicity, time is designated the primary index as the most-limiting research resource.

Based on the productivity measure and the most-limiting research resource, the efficiency of a research strategy, $\underline{E}$, is then defined as:

$$E = \Delta P/(T_1 + T_2) \qquad [11.2]$$

where T_1 is the time elapsed from the initiation of research to the time the new technology is developed, and T_2 is the time elapsed from the development of the new technology to the time it is actually adopted by farmers.

The measure of efficiency is based on the concept that the improvement in farm productivity does not occur immediately after the discovery of a more productive technology but only after it has been actually adopted by farmers on their own farms. Thus, the time frame used in equation 11.2 is the sum of T_1 and T_2 representing the whole duration of time from the initiation of research to the time the output is actually adopted by farmers. This is in contrast with the traditional concept of research in which technology generation is the primary concern and technology verification and dissemination are considered as being outside the research domain. Thus, in traditional research, time includes only T_1, and T_2 is considered as zero. Recently, however, research workers as well as policy makers have been frustrated by the slow pace with which the output of technology generation research has been adopted. Consequently, there is a growing tendency to expand the research domain to include not only the development of new technologies but also the process of convincing the farmers to adopt them. It is on this basis that the efficiency measure given in equation 11.2 is defined.

Developing a Research Strategy

In the development of a research strategy, two components need to be defined: first, the available research resources; and secondly, the research activities to which the resources can be allotted.

Research Resources

The existing research institutions constitute the main bulk of the resources available for research in multiple cropping. For most of the developing countries, there are two groups of institutions that provide significant input to their agricultural research. These are the National Agricultural Research Centers (NARC) and the International Agricultural Research Centers (IARC), which can be distinguished from each other by certain contrasting features (CGIAR 1977) in staffing, target area, and research focus and financial support.

NARCs are primarily staffed by researchers from within the country, whereas the IARCs have access to the best scientists from all over the world. Consequently, the quality and level of expertise among the senior staff of an IARC are expected to be better than that of a NARC.

IARCs are established on the basis of a clearly defined problem covering many countries and a wide geographical area, whereas the NARCs are established to solve important national problems with very little regard for the applicability of its findings to solve problems of other countries.

Funds for the IARCs, which are provided by donors from all over the world, are usually adequate to support all the required research activities in its well-defined and sharply focused area of concern. On the other hand, funds for the NARCs which are primarily provided by the national government, are often less than adequate to finance all the research required to address the wide range of problems that they are expected to solve.

Research Activities

The three research activities in multiple cropping which need to be considered in the development of a research strategy are technology generation, technology verification, and environmental classification. Of these, the first two were described in Chapters 7 and 8, respectively, and need no further elaboration.

The third activity, environmental classification, is concerned primarily with the development of functional relationships between crop productivity and environment. It has a close relationship and a significant effect on research in both technology generation and verification. With a reliable functional relationship between crop performance and environment, the best production technology for any specified location could be readily identified, and the time required for both technology generation and verification could be significantly shortened. If the functional relationship has such a high degree of reliability over a wide range of environment that the performance of a production technology can be accurately predicted for any specified environment, then the process of technology verification could be eliminated altogether.

Estimating the Efficiency of Each Research Activity

The relative efficiencies of the different research activities in improving farm productivity are the primary bases for developing a research strategy. Thus, those research activities with higher efficiency should be given priority over, and more resources than, those with lower efficiency. The procedure for estimating the efficiency of each of the three research activities in contributing to the improved farm productivity is illustrated. The step-by-step procedures are described for estimating the efficiency of each activity using data taken mainly from rice experiments at Los Baños, Philippines, summarized in Table 11.1.

Step 1 - Determine potential yield as the highest annual yield that could be obtained from the crop.

In irrigated rice, the potential yield is estimated at 35.41 t/ha/yr based on the assumptions that four crops of rice can be harvested per year; that under optimal management practices, solar radiation is the main factor limiting yield (Evans and De Datta 1979); that maximum yield per crop is 11.0 t/ha when the crop is grown during the months of high solar radiation (IRRI 1973); and that maximum yield per crop during the months of low solar radiation can be computed using the linear relationship between yield and solar radiation of Yoshida (1980).

Table 11.1. The efficiencies of the three research activities[1] in increasing farm productivity in irrigated lowland rice

Item[2]	Efficiency value	Source
(A) Potential yield	35.41	IRRI 1973; Yoshida 1980
(B) Best farm yield	18.37	Gomez et al. 1979
(C) Average farm yield	7.95	Gomez et al. 1979
(D) Potential impact of TG	17.04	(A-B)
(E) Potential impact of TV	10.42	(B-C)
(F) Research time for TG (yr)	12.00	Assumption
(G) Efficiency of TG	0.71	1/2 (D/F)
(H) Research time for TV (yr)	4.00	Assumption
(I) Efficiency of TV	1.30	1/2 (E/H)
(J) Time reduction in TG due to EC	4.00	Assumption
(K) Improved efficiency of TG due to EC	1.06	1/2 [D/ (F-J)]
(L) Time reduction in TV due to EC (yr)	2.00	Assumption
(M) Improved efficiency of TV due to EC	2.60	1/2 [E/ (H-L)]

[1] Technology generation (TG), technology verification (TV), and environmental classification (EC).

[2] Unless specified, the unit is t/ha/yr.

Step 2 - Estimate economic farm yield as the highest farm yield that is also profitable for farmers to produce (see Figure 8.1).

For irrigated rice, the economic farm yield is estimated at 18.37 t/ha/yr based on results from the yield constraint trials conducted in Laguna, Philippines (Gomez et al. 1979), although this is slightly lower than the 23.6 t/ha/yr obtained from the IRRI rice garden (Morooka et al. 1979). It is assumed that three crops can be harvested per year with the third crop giving the same yield as the dry-season crop.

Step 3 - Estimate actual farm yield.

For irrigated rice, the actual farm yield is estimated at 7.95 t/ha/yr based on data from farmers' fields in Laguna, Philippines (Gomez et al. 1979).

Step 4 - Determine the efficiency of technology generation research through the following processes:

a) Compute the potential effect on yield of technology generation research as the difference between potential yield and economic farm yield (i.e., the technology gap). The major function of the technology generation research is to develop new production technologies that will reduce the usually high cost of bridging the technology gap.

Using the figures from steps 1 and 2, the potential effect of technology generation research is 35.41 - 18.37 = 17.04 t/ha/yr, which represents the additional yield that farmers can economically produce had they adopted the appropriate technology.

b) Estimate the research time required to develop a technology that can bridge one half of the technology gap estimated in step 4a. For the present example of rice, this time is set at 12 years.

c) Compute the efficiency of technology generation research as the ratio of one-half of the technology gap and the research time required; (17.04)/(2)(12) = 0.71 t/ha/yr.

The computation of the efficiency index was based on the assumption that the technology generation research is expected to bridge one half, instead of the whole, of the technology gap. This assumption was made for two reasons: First, the bridging of the first half of the technology gap is more realistic since it is expected to be much easier to accomplish than the second half. Secondly, the time required to bridge the first half can be more accurately estimated.

Step 5 - Determine the efficiency of technology verification research as follows:

a) Compute the potential impact on yield of technology verification research as the difference between economic farm yield and average farm yield (i.e., the adoption gap). The major function of the technology verification research is to accelerate the adoption by farmers of new technologies which will result in the reduction of the magnitude of the adoption gap.

Using the figures from steps 2 and 3, the potential impact of technology verification research is computed as 18.37 - 7.95 = 10.42 t/ha/yr, which represents the additional yield that can be attained by the farmers if the presently available pool of economically feasible technologies (developed through technology generation research) is adopted on all farms.

b) Estimate the research time required to increase farm yield by one half of the adoption gap. For the present example, this time is set at four years.

c) Compute the efficiency of technology verification research as the ratio of one half of the adoption gap and the research time required: (10.42)/(2)(4) = 1.30 t/ha/yr.

Step 6 - Determine the efficiency of environmental classification research as follows:

a) Find the reduction in research time due to the development of reliable functional relationships between yield and environment (i.e., environmental classification). In this case, this time reduction is assumed to be four years for technology generation and two years for technology verification.

b) Compute the improved efficiencies of technology generation and verification research using the reduced research time due to the presence of environmental classification research. In this case, improved efficiency of technology generation research is (17.04)/(2)(8) = 1.06 t/ha/yr; and that of technology verification research is (10.42)/(2)(2) = 2.60 t/ha/yr.

Because the environmental classification research reduced the time required for technology generation and verification activities by one-quarter and one-half, respectively, their efficiencies are also increased proportionately.

Proposed Research Strategy

The research strategy for multiple cropping must address the three research activities simultaneously, because they are so closely related that progress in one is greatly dependent upon that in the others. For example, the benefit from technology verification research is greatly influenced by the productivity of new technology developed in the technology generation phase and the reliability of the environmental classification research. The more productive is the new technology, the greater is the chance that it will be adopted by farmers, and the larger is the expected improvement in the farm yields. On the other hand, the development of new technologies is also greatly enhanced by an accurate identification of the major constraints to farm yields, information which can be conveniently obtained through feedback from technology verification research.

The research strategy proposed for multiple cropping is developed based on the relative efficiencies of the three research activities computed for rice (see Table 11.1), which have been shown by Gomez and Zandstra (1980) to be also applicable to other crops such as rain-fed rice and corn. The proposed research strategy is described in three parts.

First, the NARCs should immediately increase their investment on technology verification research, for two compelling reasons. First, this research activity is estimated to have a larger and more immediate effect on actual farm yields relative to that of technology generation or environmental classification research. Secondly, the research techniques required for technology verification (see Chapter 12) are fairly standard and can be implemented with the minimum of highly trained manpower.

Second, the IARCs should concentrate on technology generation research. With good access to the best minds all over the world, the IARCs are in a better position to use creativity in discovering new and more productive technologies. Furthermore, although the efficiency of technology generation research is relatively low and not so attractive from the viewpoint of the NARCs, its actual potential for improving agricultural productivity is in fact estimated to be 64% higher than technology verification (see Table 11.1) making it a very attractive challenge for the IARCs.

Third, both the NARCs and the IARCs should cooperate with each other on environmental classification research. The NARCs, with their extensive network of experiments both in research stations and in farmers' fields, are in a good position to obtain data on the crop performance and the corresponding environment in many locations. The IARCs, on the other hand, should be in a strategic position to provide the expertise and the financial support required for analyzing and rationalizing the voluminous data into meaningful and reliable functional relationships between crop performance and environment.

PART III

TECHNOLOGY VERIFICATION AND DISSEMINATION

THE PHILIPPINE EXPERIENCE

CHAPTER 12: RESEARCH NETWORK FOR TECHNOLOGY VERIFICATION

On the assumption that the technology best in research stations is also the best in farmers' fields, agricultural researchers have traditionally concentrated their efforts on experiments in research stations. With this tradition, the investment in research for technology verification in farmers' fields has been negligible. For example, in the improvement of the national research system in the Philippines in the 1970s, a substantial investment was allotted to the upgrading of the physical and manpower facilities of the existing research institutions, almost all of which are experiment-station-type facilities (Drilon 1978). Yet the effect of technology verification research on farm productivity has been estimated to be twice that of technology generation research (see Chapter 11).

In the late 1970s, recognizing the need to shift the emphasis of agricultural research from technology generation in experiment stations to technology verification in farmers' fields, the Philippine government encouraged the conduct of applied research in farmers' fields and established, in a few pilot provinces, the necessary facilities for conducting on-farm experiments that are designed to verify the applicability to the local environment of some promising technologies developed elsewhere. This chapter describes the experiences of the Philippines in conducting technology verification experiments and in establishing a national research network for technology verification.

Results of Technology Verification Experiments in the Philippines

Technology verification experiments in farmers' fields, following the aims and procedures described in Chapter 8, were originally conducted in lowland rice farms (De Datta et al. 1979a, 1979b, 1979c; Gomez et al. 1979), and subsequently for corn (Mercado 1981) and for multiple-cropping conditions (Gomez 1979). The results of these three series of experiments are discussed in the succeeding sections.

Technology Verification in Lowland Rice

The biological and socioeconomic constraints responsible for low yields in the lowland rice farms were extensively studied in technology-verification-type experiments conducted in four provinces of the Philippines from 1974 to 1977 (De Datta et al. 1979a, 1979b, 1979c; Gomez et al. 1979). These trials were designed to compare the productivity of the farmers' existing practices with that of the new technology. The new technology consisted mainly of improvements in fertilization, insect control, and weed control. The complete factorial, minifactorial, and supplemental sets of treatments (see Chapter 8) were tested, and the results are summarized in Table 12.1.

The major findings are that, first, the yield gap (i.e., the difference between the new technology and the farmers' existing prac-

Table 12.1. Estimated yield gap in lowland rice and the major test factors contributing to the yield gap, in four provinces of the Philippines from 1974 to 1977

Item	Nueva Ecija	Laguna	Camarines Sur	Iloilo	All
Wet season					
Number of trials	54	41	27	23	145
Farm yield (t/ha):					
New technology	4.3	5.5	3.9	4.8	4.6
Farmers' practice	3.3	3.7	3.4	3.5	3.5
Yield gap (t/ha) due to:					
All test factors	1.0	1.8	0.5	1.3	1.2
Fertilization	0.3	0.5	0.0	0.5	0.3
Insect control	0.5	0.9	0.2	0.4	0.5
Weed control	0.1	0.2	0.0	0.3	0.1
Added output value ($/ha)	130	209	61	156	144
Added input cost ($/ha)	123	182	84	151	137
Added return ($/ha) from:					
All test factors	7	27	-23	5	6.8
Fertilization	4	59	-56	17	10.4
Insect control	-7	-34	-44	-52	-28.7
Weed control	-2	23	-9	25	8.0
Dry season					
Number of trials	28	28	20	11	87
Farm yield (t/ha):					
New technology	6.8	6.5	5.6	5.4	6.2
Farmers' practice	4.7	4.4	3.5	3.8	4.2
Yield gap (t/ha) due to:					
All test factors	2.1	2.1	2.1	1.6	2.0
Fertilization	1.0	0.9	1.0	1.0	1.0
Insect control	0.8	0.7	0.6	0.2	0.6
Weed control	0.2	0.1	0.2	0.2	0.2
Added output value ($/ha)	273	274	242	187	255
Added input cost ($/ha)	142	190	209	185	178
Added return ($/ha) from:					
All test factors	131	84	33	2	77
Fertilization	117	113	68	62	97
Insect control	36	-74	-34	-79	-30
Weed control	29	14	14	18	19

Adapted from De Datta et al. (1979a, 1979b, 1979c); Gomez et al. (1979); and Herdt (1979).

tice) was generally higher in the dry season (2.0 t/ha) than in the wet season (1.2 t/ha). Secondly, improved fertilization and improved insect control were the most important contributors to the yield gap during the dry and wet seasons, respectively. Thirdly, the return to cost was generally positive and high for improved fertilization specially during the dry season. That for insect control, however, was generally negative indicating that, although the improved technology for insect control could increase farm yield, it was too costly for farmers to adopt.

Technology Verification in Corn

Mercado (1981) studied extensively the production factors responsible for low corn yields in farmers' fields in the Philippines. Using only the mini-factorial treatment set (see Chapter 8) consisting of five test factors, variety, fertilization, weed control, insect control, and planting method, technology verification trials were conducted in farmers' fields all over the Philippines. The results, summarized in Table 12.2, indicate that, first, the adoption of the new package of technology improved farmers' yields by an average of

Table 12.2. Estimated yield gap in corn and the contribution of the five test factors to the yield gap, in 21 provinces of the Philippines from 1976 to 1977

Item	Amount
Number of trials	52
Farm yield (t/ha):	
New technology	3.02
Farmers' practice	1.76
Yield gap (t/ha) due to:	
All factors	1.26
Fertilization	1.05
Variety	0.77
Weed control	0.61
Planting method	0.50
Insect control	0.57
Added output value ($/ha)	200.53
Added input cost ($/ha)	115.94
Added return ($/ha) from:	
All test factors	84.59
Fertilization	100.78
Variety	99.14
Weed control	67.95
Planting method	63.11
Insect control	56.32

Adapted from Mercado (1981).

1.26 t/ha. The two largest contributors to this yield gap were improved fertilization and improved variety. Secondly, the interaction among test factors was large. This is indicated by the fact that the total yield gap (1.26 t/ha) was substantially lower than the sum of the contributions to the yield gap of each test factor (3.50 t/ha). However, because only the mini-factorial set of treatments was tested on all farms, individual interactions among test factors could not be measured.

Technology Verification in Multiple Cropping

With the potential for large interactions among crop components in a cropping pattern, it is not advisable to derive an estimate of yield gap in multiple cropping from the yield gap estimates of monocrops. It is necessary to compare directly the new cropping pattern as a whole with that of the farmers, especially if the results of this comparison are to be used as the basis for developing the recommended production technology. Based on this premise, Santos and Gomez (1981) compared the farmers' rice - mung-bean cropping pattern (a common cropping pattern in Urdaneta, Pangasinan), to a new technology involving the same cropping pattern but with improvements in six component technolo-

Table 12.3. Estimated yield gap and economic benefit from each test factor in a technology verification trial involving the rice - mung-bean cropping pattern in Urdaneta, Pangasinan, Philippines from 1979 to 1980

Item	Rice	Mung beans
Number of trials	4	4
Yield of new technology (t/ha)	3.65	1.08
Yield of farmers' practice (t/ha)	3.10	0.76
Yield gap (t/ha) due to:		
All test factors	0.55	0.33
Insect control	-0.11	0.09
Fertilization (rice)/variety (mung beans)	0.17	0.32
Weed control (rice)/land preparation (mung beans)	-0.35	0.05
Added output value ($/ha)	73	176
Added input cost ($/ha)	237	1
Added return ($/ha) from:		
All test factors	-164	175
Insect control	-104	53
Fertilization (rice)/variety (mung beans)	-47	160
Weed control (rice)/land preparation (mung beans)	-121	48

Adapted from Santos and Gomez (1981).

gies; fertilization, insect control, and weed control in rice, and variety, insect control, and land preparation in mung beans. The mini-factorial treatment set (see Chapter 8) was used in all test farms. The results, summarized in Table 12.3, indicated first, that rice yields were not substantially improved by the new management practices, but that the yields of mung beans were increased by 42%. Secondly, in the mung-bean crop, the use of improved variety gave the largest contribution to the yield gap. Thirdly, the yield gap in each component crop differed widely, from the sum of the contributions of individual test factors, indicating the presence of a large interaction among test factors in both crops. But, as in the technology verification trials in corn, because only the mini-factorial treatments were tested in all farms, individual components of interaction could not be evaluated for any of the crops.

The Establishment of the National Research Network For Technology Verification

With the realization that technology verification is essential for developing production packages better than the farmers' existing practices, and that technology verification research can increase farm productivity faster than traditional technology generation research, the Philippine government initiated, in 1980, the establishment of a national research network for a systematic verification of the crop-production technologies in different parts of the country. The procedure for technology verification described in Chapter 8 was the primary basis for developing this network, which was designed to compare, under actual farm conditions, the productivity of a new technology package to that of the farmers' existing practices, and to determine the major constraints to the rapid adoption by farmers of technology packages shown to be better than their own.

The procedure used in the national research network follows the multiple-cropping research approach in that the technology package to be compared to the farmers' existing practices is assembled at the cropping-pattern level. The primary criterion for evaluating the suitability of a new technology package is the magnitude of its superiority over the farmers' existing practices, because this must be large enough to motivate farmers to change from their traditional practices to those that are new and unfamiliar. In practical terms, this translates into two specific operational rules.

First, the net income from the new technology must exceed that from the farmers' existing practices by at least 30%.

Second, the contribution to the yield gap is evaluated separately for each test factor and only factors that satisfy at least *one* of the following three conditions would be considered for inclusion in the recommended package of technology: 1) the contribution to the yield gap is at least 30% of the monetary value of the present farm yield; 2) the contribution to the yield gap is at least 30% of the monetary value of the total yield gap; and 3) the benefit-cost ratio must exceed 1.5.

The procedure used in the national research network also stressed the importance of conducting technology verification experiments in as many locations as possible in order to develop production packages that are uniquely suited to specific biophysical and socioeconomic environments. The Philippine national research network for technology verification was seen as providing the necessary facilities from which to conduct verification trials in each of the 77 provinces of the country. Each province would have a research team capable of conducting verification trials in at least one target area at any one time. The facilities required for such a technology verification research network are described in the succeeding section, using as illustration the experience of the Philippines in eight pilot provinces.

Physical Facilities

The physical facilities needed for a technology verification research network are relatively small. The primary facility needed is a set of sample farms upon which both the farm surveys and the field experiments can be conducted. As sample farms, their natural state should be retained and no deliberate physical changes should be initiated. Thus, expensive investments such as land development and construction of structures, usually required in the research network for technology generation, are not necessary and, in fact, should be avoided in the research network for technology verification. However, technology verification researchers must be able to visit the scattered sample farms, so that they can supervise closely the day-to-day operations and the measurement of data. Each research team in the Philippine national research network is provided with the following facilities.

a) A field headquarters within the target area, where the researchers have an office, store their equipment, hold regular meetings, and work on their research data.
b) A motorcycle for each researcher so that he can visit his field experiments; and one four-wheeled vehicle for each research team to facilitate the transport, to each sample farm, of supplies and materials needed.
c) Equipment, such as rain gauge, evaporation pan, and pH meters, for the measurement of soil and weather parameters.

Technical Personnel

The technical personnel who operate the Philippine national research network for technology verification can be classified into two groups, the research site team and the national coordinating team.

The National Coordinating Team. The national coordinating team (NCT) is composed of the national coordinating committee, a pool of consultants, and the field coordinators.

The national coordinating committee is the policy-making body of the network and acts on such matters as the selection of technology packages to be verified, the choice of the target area in which the packages are to be tested, and the final packaging of the technology to be recommended for adoption. The national coordinating committee for the eight pilot provinces was composed of representatives of both extension and research institutions, namely: the International Rice Research Institute, the Philippine Council for Agriculture and Resources Research, the Bureau of Plant Industry, the Bureau of Agricultural

Extension, the National Food and Agriculture Council, and the University of the Philippines at Los Baños.

The consultants are hired on a part-time basis, and their services are used mainly to design experiments to answer specific problems at a research site; to participate in the annual review and the planning conferences at the research sites; and to advise the national coordinating committee on selecting the cropping patterns and the corresponding management practice that are ready for general adoption by farmers. Consultants with expertise in crop production and in agricultural economics were the most sought after in the initial stages of technology verification in the eight pilot provinces in the Philippines.

The field coordinators are full-time personnel who act as the secretariat of the NCT. Their main function is to act as the liaison officers for the various research-site teams so that their problems, whether administrative or technical, are brought quickly to the attention of the appropriate authorities. With the assistance of the field coordinators, the field researchers are partially freed from the time-consuming task of speeding the flow of papers and information between research sites and the regional and national offices. Initial experience in the eight pilot provinces showed that the liaison officers were very valuable in facilitating solutions to both financial and technical problems. For example, they provided valuable services in facilitating the timely release of research funds and in providing the research-site teams with technical information required in the planning and conduct of experiments. Experience in the eight pilot provinces also indicated that at least one field coordinator should be assigned to each of the 12 regions of the country.

The Research-Site Team. The research-site team (RST) is composed of full-time field researchers assigned to a specific target area. They are either hired directly by the national research network or are detailed to the network by the existing research or extension organizations. They hold office at the target area and their functions are to conduct and supervise the farm surveys and field trials, to collect and summarize all required data, and to perform other activities that may be assigned to them by the NCT.

The number of field researchers per team should be proportional to the number of test farms in each target area. From the experience in the eight pilot provinces, it is estimated that 10 to 15 test farms can be handled by one full-time field researcher. Thus, for each target area having 50 or fewer test farms, a research-site team composed of three field researchers should be adequate.

In the eight pilot provinces, each RST had three members, the majority of whom were permanent employees of the Ministry of Agriculture and who were assigned to work full time in the national research network. Each had undergone a 10-week training on research methods in multiple cropping with major emphasis on technology verification. Each member of the RST handled a minimum of 10 verification trials.

On the assumption that one RST will initially be assigned to each province, the personnel requirement for all 77 provinces in the Philippines would be a total of 231 technical personnel. Hence, it is unlikely that each province can initially conduct technology verification research on more than one target area. At the initial stage, the single target area of each province is usually allotted to those cropping patterns that involve its most important crop. As the recommended package of technology for this initial target area is verified, then a new target area corresponding to its second most important crop can be worked on, and so on.

Administrative Facility

In the Philippines, as in other developing countries of Asia, the research and extension organizations are very distinct and separate institutions. This tradition dates back to the time when agricultural research was mainly concerned with technology generation which does not require a close and sustained interaction between researchers and extension workers. However, with the current emphasis on technology verification conducted over a large number of sample farms with results which may immediately be used by extension workers, it is imperative that researchers and extension workers must continuously interact with each other. Thus, a major function of the national research network for technology verification is to facilitate and bring to the institutions this close working relationship.

Two key features are incorporated in the structure of the national research network that ensure this continuous interaction between researchers and extension workers. The first is the strong representation of the extension organization in the national coordinating committee, which emphasizes the fact that the network is not purely a research organization. It is, therefore, essential that the representation of the extension organization in the committee be fairly strong and, whenever possible, the chairman of the committee should come from the extension organization.

The second feature is the active participation of extension technicians at the research site (i.e., the RST is composed of both research and extension personnel of the Ministry of Agriculture). Although the extension technicians work as full-time researchers during the period of their assignment to the network, their experience on technology verification should improve their understanding and their receptivity to new technologies when they return to their permanent jobs.

CHAPTER 13: PILOT PRODUCTION PROGRAMS

The ultimate success of an improved technology is determined not from good results in a few selected farms, but rather from its widespread adoption by a large number of farmers. Unfortunately, the superiority of a new technology over the farmers' existing practice, as indicated by the technology verification trials, does not automatically ensure its adoption. This is especially so for multiple-cropping technologies, the adoption of which usually requires cultivation of new crops that may not be familiar to the farmers, additional labour and cash inputs, and timely implementation of the required practices.

Although easily satisfied when only a few farms are involved, the problem is greatly complicated when the new technology is adopted by the majority of farmers in the same community. For example, the needs for more labour for the cultivation of an additional crop and for marketing channels to sell new farm products become more difficult to satisfy if they are required simultaneously by the majority of farmers in the same community. The labour available in the community may not be enough to satisfy the increased needs of all farmers during the peak periods. Furthermore, the volume of new products to be sold may be too large both for existing and for newly developed markets to absorb. Hence, the potential constraints for rapid adoption of a new and more productive technology must be studied at the community rather than at the farm level. This is usually accomplished through a pilot production program, covering a few selected communities, where farmers' reaction to, and actual benefits from, the use of a new technology can be critically evaluated and used as a basis for designing a full-scale national production program. The process of designing such a program is discussed and the procedures for its implementation are illustrated from experiences in the Philippines.

Major Features of a Pilot Production Program

Agricultural production programs are designed to develop rural communities by improving their farm productivity (Gomez et al. 1981). Increased productivity is attained by getting farmers to adopt new production technologies that are more productive than their existing practices. For multiple-cropping production technologies, in which the widespread adoption by farmers may require institutional changes in the community, a pilot production program conducted in a few selected communities is a useful basis for designing a full-scale national production program. The objectives of a pilot production program (Zandstra 1980; Gomez et al. 1981) are three-fold:

a) To determine the institutional and social requirements for the accelerated adoption of a new technology. Some of these are the necessary improvements in the extension, credit, market, and community organizations; the management structure needed to ensure the timely delivery of the production inputs; and the cost of introducing these changes.

b) To evaluate the benefits derived by the farmers and the community from the adoption of the new technology.
c) To determine the major constraints to adoption (i.e., the reasons why farmers are not adopting the new technology).

The four essential features that must be included in the design of a pilot production program to achieve the above objectives, are discussed in the succeeding sections.

An Improved Technology

An important ingredient in a pilot production program is a production technology that is substantially better than the farmers' existing practice. They cannot be expected to change their traditional practice, with which they are very familiar and which has served them well for years, unless they are thoroughly convinced that the new one is substantially more productive under their own farm conditions.

In a pilot production program, the new technology takes the form of a set of recommendations for either a single crop or for the whole cropping pattern (Denning 1981). Usually derived from the results of technology verification trials, they must ensure first, that the recommended technology gives higher yields and higher net profits relative to the farmer's existing practice, and secondly, that all of the additional inputs required by the new technology can be satisfied by the community and its supporting institutions.

The Community as Its Focus

In contrast to the conduct of field trials in which a single farm is the experimental unit, the whole community becomes the unit of evaluation in a pilot production program. Both the program implementation and its evaluation must be designed such that it results are community-wide in scope and in meaning.

With the community as the focus of a pilot production program, the area of coverage of a pilot community must not be smaller than the smallest unit of government (e.g., barangay in the Philippines, ward in Nepal, desa in Indonesia, and jangwat in Thailand). In fact, if the program is concerned with support institutions the evaluation of which requires an area larger than the smallest unit of government, then the coverage of one pilot community may consist of a cluster of units of government adjacent to each other. For example, if extension services were being examined and if the ideal size for coverage by one extension technician were three barangays, then the area of coverage of one pilot community should necessarily not be smaller than three barangays.

Support Services

New recommended technologies, with potential productivities shown to be substantially better than the farmers' existing practices, usually require more input of labour and materials, improved management, and better markets than existing practices. Consequently, a pilot production program designed to accelerate farmers' adoption of a new technology must ensure that the added requirements could be satisfied either from existing institutions or, if necessary, from newly established ones. The following support services are usually required by a pilot production program concerning multiple-cropping technologies (Zandstra 1980; Denning 1981).

Extension Service. The extension technician provides information on production technologies for many farmers in rural communities of Asia. This need is even greater in a pilot production program in which more information has to be communicated quickly and effectively to the farmers in the pilot communities.

For a pilot production program involving multiple-cropping technologies, which are usually more complex than the existing practice, the extension technician must be thoroughly familiar with the technology and the extension mechanism for its dissemination if he is to accelerate the farmers' shift from the existing practice to the recommended one. Thus, a common feature of most pilot production programs, is a carefully planned short-term training for extension technicians, designed to familiarize them thoroughly with the recommended technology, the support services required, and the mechanism for convincing farmers to adopt the technology.

Input Supply. For multiple-cropping technologies, a major requirement for their sustained adoption is an assurance that additional inputs are available in sufficient quantities, at the right place (accessible to farmers), and at the proper time. Hence, it is important that the pilot production program must have advance estimates of all inputs required by the farmers in the pilot community to have enough lead time to ensure their availability whenever needed. For example, quality seeds of new varieties and even new species are a vital requirement of most multiple-cropping programs. The seed requirement must, therefore, be estimated early enough to give time for the suppliers to produce the seeds on time and in sufficient quantities for use by the farmers in the program.

Credit. The availability of credit is an important prerequisite to the adoption of a recommended technology, because most farmers in the developing countries of Asia have insufficient cash resources to satisfy the added input requirements. Even for those who have the required cash, availability of credit is still a major motivation for adoption. The willingness of the financial institutions in the area to participate in the implementation of the new technology gives farmers added assurance regarding the profitability of the recommended technology.

In a multiple-cropping pilot production program, for which primary target farmers are usually those with small holdings and limited resources, the credit facility must not require substantial collateral and must be capable of quickly processing small loans from a large number of farmers. Because these requirements are usually not acceptable to private lending institutions, government funding may be needed to cope with the high risk and the substantial overhead cost of granting small loans with minimum collateral.

Market. A successful pilot production program will see a substantial increase in farm productivity, a large portion of which may need to be sold outside the community. For a multiple-cropping program, the farm products may involve new crops, marketing channels for which may not be familiar to the farmers concerned. Thus, an important feature of a pilot production program is a mechanism that will ensure a ready market for the additional products. Some examples of the different types of market intervention in pilot production programs used successfully in the Philippines are the direct purchase of farm products by the pilot production program, the arrangement of marketing contracts between farmer cooperators and the major users of the farm products, and the reduction in cost of transporting farm products to market by improving the efficiency of the existing transportation facilities.

Coordination and Management. With the many institutions, both public and private, involved in the implementation of a pilot production program, an effective coordinating mechanism must be provided to ensure that each participating institution assumes and executes its specified responsibility in coordination and in harmony with the others.

A useful approach to coordination and management is to form a management committee to advise on program policy, composed of local farmers, local political leaders, and heads of participating institutions. Its primary responsibility should be to define the scope of the program and the specific task for which each participating agency assumes responsibility.

Monitoring and Evaluation

The primary objective of a pilot production program is to increase the level of farm productivity in the pilot communities. At the community level, productivity is a function of the number of farmers who adopt the new technology and the added benefit that accrues to each. The following indices should be measured periodically to evaluate the program's effect on farm productivity.

Adoption by Farmers. A useful parameter is the percentage of farmers in each pilot community who have adopted the recommended package of technology. Because this may consist of several component technologies, and a farmer may adopt the technology either partially by component or completely as a package, the status of adoption by each farmer should be rated on the basis of each component technology. For example, if the farmer's existing practice is a rice - corn cropping pattern and if the recommended technology is a rice - rice cropping pattern (see Case II in Chapter 8), then adoption by farmers must be evaluated on the basis of component technologies -- cropping pattern, i.e., the planting of rice instead of corn as the second crop; fertilization; insect control; and land preparation. In practice, a random sample of 100 to 200 farmers in each pilot community should be evaluated in determining the degree of adoption by farmers.

Crop Yield. Yields of each crop, both from those who do and those who do not adopt new technology, should be measured, preferably through a crop-cutting method. In practice, yields are usually determined for 20 adoptive and 20 non-adoptive farmers in each pilot community, selected at random from the larger sample used for determining adoption by farmers. If there are not enough to satisfy the requirement of 20 adoptive and 20 non-adoptive farmers, additional samples can be selected randomly from other farmers.

Farm Income and Other Benefits. A brief questionnaire should be prepared to obtain information on income and other benefits derived from farm activities. In practice, the same sample farmers used for determining crop yield are used for this interview. For each adoptive farmer additional questions should be asked regarding his previous practice and its productivity relative to the new technology.

Reasons for Non-adoption by Farmers. Those who do not adopt a new technology should be queried as to their reasons. In practice, the same sample of 20 non-adoptive farmers, used for determining crop yield, is also used here.

The Philippine Experience

Several pilot production programs designed to evaluate the requirements and effects of introducing multiple-cropping technologies in selected communities have been implemented in the Philippines. Two such programs are the UPLB Project (Gomez 1978) and the KABSAKA Project (Pantastico et al. 1979) described in subsequent sections.

The UPLB Project

From 1972 to 1978, the University of the Philippines as Los Baños (UPLB), with financial support from the International Development Research Centre (IDRC), conducted studies on the adoption of multiple cropping and its effects on selected communities in the Philippines (Gomez 1978). The main objective was to determine why multiple cropping, which is uniquely suited to small farms with abundant labour supply, and which has repeatedly shown excellent potential in research station experiments, has not been widely adopted in the Philippines where farm size is small and population density is high.

Methodology. The approach was to treat the whole community, rather than a field or a farm, as the experimental unit. The barangay, the smallest unit of government in the Philippines, was used as the community unit. Six barangays in the province of Laguna and Batangas were selected as pilot communities. The significant features of these communities are rain-fed rice as the main crop; high accessibility to market; dense population (916 persons/square mile); small farm size; low productivity; and large household size (Table 13.1). These features were deliberately used as the criterion for selection of the pilot communities because they were considered favourable for the rapid adoption of the multiple-cropping technology.

To encourage farmers to shift from their existing practices to the recommended multiple-cropping technologies, the project provided each pilot community with important services.

Table 13.1. Some characteristics of the six pilot communities at the start of the UPLB Project in 1972

Characteristic	Amount
Land area per community (ha)	292
Farm size (ha)	1.9
Rice yield (t/ha)	1.9
Number of households per community	418
Household size (No.)	6.4
Annual household income ($)	891
Annual household food expenses ($)	360
Household facilities ($)[1]	82
Distance to nearest market (km)	4.2

[1] Value of household equipment such as stove, furniture, etc.
Source: Gomez (1978).

a) A full-time extension technician. An extension technician with a degree in agriculture, who had undergone a two-week training in crop production and extension, was assigned on a full-time basis to each pilot community. Each technician was required to reside in the community where he was assigned. His major responsibilities were to teach and assist each farmer to implement a recommended multiple-cropping technology that the farmer had chosen; to encourage farmers to form associations to facilitate the purchase of inputs and the marketing of farm products; and to assist farmers in securing institutional credit.

b) Cheap credit. Another service provided by the program was the availability of cheap credit to each farmer adopting a recommended multiple-cropping technology. To receive credit, the farmer had to present to the local bank a one-year farm plan, approved by the extension technician, outlining the cropping pattern and the component technology to be implemented. To ensure that the local banks would provide the preferential credit facility to these farmers the program opened a savings account in all participating banks. These banks were then given the authority to deduct from the savings account of the program any preferential loans that were not repaid by the farmers.

c) Improved market. The improvement of marketing channels consisted of several activities. One was the provision by the program of a vehicle for the transportation of surplus products to the nearest market. This activity lasted for about a year by which time the services of private entrepreneurs were adequate to support the needs of the community. Another activity was the formation of the farmers' association through which farmers could jointly market and negotiate the farm price of their surplus products.

Table 13.2. Measures of adoption by farmers of the recommended multiple-cropping technology in the six pilot communities in UPLB Project, 1972 to 1976

Adoption index	1972[1]	1974	1976
Multicropped area (%)	48	62	75
Crop-intensity index[2]	1.65	1.92	2.10
Farmer cooperators (No.)	29	490	656
Guaranteed loan ($1000)	0.00	16.90	12.40
Repayment rate (%)	-	85	88

[1] The year the project started.
[2] Average number of annual crops grown and harvested per year in a sequential-cropping pattern.
Source: Gomez (1978).

Two indices, productivity and nutritional status, were used as the main criteria for success or failure of the program. Productivity included rate of adoption, cropping intensity, biological yields, value of product, and net income. Nutrition was measured by the height and weight of pre-school children and eating habits of the farm household. Both productivity and nutrition indices were measured at the start of the project and every year thereafter.

Results. The farmers' response to the program was enthusiastic. Adoption of the recommended multiple-cropping technology was rapid. The accompanying improvements in both productivity and nutritional status, and the role of the extension technician in catalyzing these improvements, are discussed.

a) Productivity. The number of farmers who shifted from their traditional practices to the recommended multiple-cropping technologies (i.e., cooperators) accelerated very quickly over time (Table 13.2). Correspondingly, there was a rapid increase in the percentage of multi-cropped area and in the crop-intensity index. To compare the farm productivity of those who adopted the multiple-cropping technology (cooperators) with those who did not (non-cooperators), 23 cooperators and 21 non-cooperators were closely monitored over a period of four years. The results show that the crop-intensity index and the productivity per farm of the farmer cooperators were much higher than those of the non-cooperators (Table 13.3). Also, the rate of increase in farm productivity was much faster for the cooperators (235% in four years) compared to that of the non-cooperators (153% in four years).

The potential for multiple-cropping technology to increase farm productivity in the project area is illustrated by the experience of Mr Selmo Javier, one of the most successful farmers in the pilot communities. Mr Javier owned 1.2 ha of rain-fed paddy in the town of Cabuyao in the province of Laguna. Traditionally, he planted only one crop of rice per year with the field left idle during the

Table 13.3. Productivity and nutritional status of 23 cooperators and 21 non-cooperators in the six pilot communities of the UPLB Project, 1973 to 1976

Indicator	Cooperators					Non-cooperators				
	1973	1974	1975	1976	Ave.	1973	1974	1975	1976	Ave.
Family size (No.)	6.8	7.2	7.5	7.7	7.3	6.3	6.7	7.2	7.3	6.9
Crop-intensity index	1.7	1.8	1.8	2.0	1.8	1.5	1.5	1.6	1.7	1.6
Number of crops grown	2.2	2.8	3.0	3.8	3.0	1.8	2.0	2.5	2.3	2.2
Value of products ($1000)										
Total	2.3	3.2	3.7	5.4	3.6	1.7	2.1	2.6	2.6	2.2
Home consumed	0.9	1.0	1.0	1.1	1.0	0.8	0.8	0.8	0.9	0.8
Nutritional status (% of normal[1])										
Height	83	86	89	91	87	80	82	85	87	84
Weight	82	85	88	90	86	80	82	85	86	83
Calorie intake	92	93	96	98	95	88	89	93	95	91
Protein intake	78	83	86	88	84	76	80	83	85	81
Vitamin intake	71	74	79	81	76	63	68	72	78	70
Mineral intake	79	78	82	84	81	74	76	80	83	78

[1] (Actual measurement/normal value) x 100, with actual measurements for height and weight taken from preschool children and for food intake taken from bi-annual recall survey; normal values were taken from the results of studies conducted by the Food and Nutrition Research Institute of the Philippines (FNRI 1974, 1979).

Source: Gomez (1978).

dry months. When the project began to introduce the recommended multiple-cropping technology in his community, Mr Javier was among the first who tried it. He planted two crops of rice, one was direct-seeded and the other was transplanted. From these two rice crops, he harvested a total of 203 cavans which gave him a net income of $973. This was a far cry from the 50 cavans he used to get from a single rice crop. After harvesting his second rice crop, Mr Javier planted watermelons on 6000 m^2 and tomatoes on another 2500 m^2 area of his field. From these two crops, Mr Javier earned an additional net income of $714.

b) Nutrition. In addition to farm productivity, the nutritional status of the 23 cooperators and 21 non-cooperators was also monitored by making a yearly measurement of the height and weight of all their pre-school children and a bi-annual recall survey of their daily food intakes. The results (see Table 13.3) indicate that:

   1) Increased productivity was accompanied by a higher food intake by the farm households and a more satisfactory nutritional status. The value of farm products consumed by the household increased almost proportionately with the increase in the total amount of farm products. Thus, whereas the percentage of farm products used for household consumption was about the same for cooperators and non-cooperators, the former consumed more in terms of absolute value than the latter.

   2) The nutritional status of families of cooperators was better than their non-cooperator counterparts. During the first year of measurement (1973), the children cooperators were found to be heavier, taller, and closer to satisfying the required daily food allowance than those of non-cooperators. Although this initial difference persisted up to the last year of measurement (1976), the advantage gained by families of cooperators over those of the non-cooperators did not increase substantially. Apparently, the effect of the pilot production program in improving the nutritional status of the farm households is not as pronounced as the improvement in productivity.

c) The extension technician. One of the most important factors that influenced the success or failure of a pilot production program was the performance of the extension technician. His technical know-how, his authority to dispense credit, and his potential to influence the input and output markets make him a powerful person in the community. He can greatly influence the rate of adoption of the recommended technology as well as the rate of repayment of loans borrowed by farmers. Experience in the UPLB project showed that the following ingredients are important toward the success of an extension technician.

   1) Accessibility. The extension technician must be easily accessible to community residents. Accessibility is greatly enhanced when he resides in the pilot community of his assignment, and as a result, is more readily accepted as a legitimate member of the community. This status greatly helps him in influencing decision making in the community. Furthermore, he is available during the late part of the day, when most farmers find it convenient for consultation and discussion.

   2) Permanence. Continuity of the technician's service to the

community is essential to his efficiency. He can not be effective if he is periodically transferred from one community to another. Experience in the UPLB project indicated that once a technician has gained acceptance in a community, that community would resent his departure making it more difficult for his replacement to regain the confidence and goodwill that the previous technician has developed. For example, three of the six pilot communities that experienced a change in the extension technicians during the first three years had a lower rate of adoption and a lower rate of repayment compared to the three other communities whose extension technicians remained in the same communities throughout the project period.

3) Developing local leaders. Experience in the UPLB project showed that, upon acceptance by the community, there is a strong tendency for the many powers and responsibilities usually exercised by indigeneous leaders of the community to be transferred to the extension technician. For example, the extension technicians were continuously pressured to lead the farmers' association, to call the farmers' meetings, and to decide on difficult problems. It is very tempting for the technician to readily accept these powers and responsibilities as part of his job, but, by yielding to this temptation, he could set back the development of indigenous and more permanent community leaders. Therefore, it is essential that the technician in a pilot production program must be able to temper his participation in local organizations such that he can effectively guide them to the correct decisions while encouraging the local leaders to bear their responsibilities and develop their capabilities.

The KABSAKA Project

In 1974, the International Rice Research Institute (IRRI), the Philippine Council for Agriculture and Resources Research (PCARR), and the Bureau of Agricultural Extension (BAE) initiated jointly a pilot production program, code-named KABSAKA[4], in nine barangays of the town of Santa Barbara, in the province of Iloilo (Pantastico et al. 1979). The objective of the KABSAKA program was to improve farm income among farmers of rain-fed rice in the pilot communities by intensifying the use of their land through multiple cropping. The recommended multiple-cropping technology was a rice - rice - upland crop pattern in lieu of the existing practice of growing a monocrop of rice.

Methodology. The procedure used to accelerate adoption of the new technology was very similar to that of the UPLB project. Each of nine pilot communities was provided with a well-trained extension technician who resided at the project site; timely credit for the needed production inputs and farm operations; reliable suppliers from whom production inputs, such as seeds, fertilizers, and herbidices could be conveniently

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[4] KABSAKA is an acronym for "Kabusugan sa Kaumahan", which means "bounty in farm".

Table 13.4. Rice yields from cooperators' fields in the KABSAKA Project

Crop year	Cooperators (No.)	Area (ha)	Rice yield (t/ha)	
			1st crop[1]	2nd crop[2]
1974-1975	2	0.27	3.0	4.0
1975-1976	9	25.0	4.0	5.0
1976-1977	54	89.0	5.2	4.0
1977-1978	88	147.0	4.9	1.6[3]

[1] Direct-seeded.
[2] Transplanted.
[3] Crop coincided with an unusually dry period.
Source: Pantastico et al. (1979).

Table 13.5. Cost and return of 30 selected cooperators, before and after participating in the KABSAKA Project

Crop[1]	Gross return ($/ha)	Material cost ($/ha)	Return over material cost ($/ha)
		Before KABSAKA (1974)	
First crop	314	39	275
Second crop	124	17	107
Total	438	56	382
		After KABSAKA (1978)	
First crop	494	105	389
Second crop	405	90	315
Third crop	121	29	92
Total	1020	224	796

[1] First crop was rice; second crop was either rice or mung beans; and third crop was any one of mung beans, cowpeas, peanuts, watermelons, corn, sweet potatoes, sorghum, squash, and eggplant.
Source: Nicolas et al. (1980).

purchased by the farmer; and ready markets for the farm products.

To monitor the effects of the project, the number of cooperators and their farm yields were recorded on a yearly basis. Also, the cost and returns of 30 cooperators at the start and at the end of the program were measured. No measurements were made on non-cooperator farmers.

Results. The project started in two barangays with two cooperators (Table 13.4). To encourage more participation in the succeeding years, an information drive was conducted among farmers in the vicinity, highlighted by a field day when the original cooperators were harvesting their bountiful first rice crops. During the third year (1976), four of the 54 cooperators started to plant upland crops after the second rice crop, and in the fourth year (1977), a total of 88 farmers joined the program. An evaluation of the farm productivity of 30 cooperators showed that the value of farm products and the return over material cost per hectare were more than doubled by the adoption of the new multiple-cropping technology (Table 13.5).

The potential of the new technology is illustrated by the experience of Mr Sobornizo, a Barangay Captain who owned four hectares of land. Before he joined the KABSAKA project, Mr Sobornizo planted rice on his land only once a year with an average harvest of 1.8 t/ha and grossed about \$800 per year. In 1976, he implemented a rice - rice - upland crop cropping pattern using corn, mung beans, and peanuts as the upland crop. He obtained a yield of 6.3 t/ha from the two rice crops and 1.6 t/ha from the upland crops. From these crops, he grossed \$3407 with a net profit of \$2000 after deducting the cost of labour and material inputs.

CHAPTER 14: NATIONAL PRODUCTION PROGRAMS

A natural sequel to a successful pilot production program is a national production program that expands the area of coverage from a few pilot communities to the major agricultural areas of the country. The national production program naturally maintains many of the features of the pilot production program such as the techniques to accelerate adoption by farmers. Nevertheless, there are two major differences. First, whereas the pilot production program by virtue of its small size, can select a small group of well-trained and highly motivated personnel, the national production program must use and contend with the rank and file of the existing extension system. Secondly, whereas the administrative set-up in the pilot production program is simple and the needed decisions can be reached quickly, the national production program must deal with the bureaucracy of large and centrally controlled national organizations. Consequently, the magnitude of success in the national production program can not be expected to be as large as that in the pilot production program.

Two alternative approaches in the design of a national production program are illustrated using the experience of the Philippines.

Approaches to Crop-Production Programs

Two alternative approaches in designing a national crop-production program are the single commodity approach, in which the main objective is to increase production of a specific crop, and the multiple-cropping approach, in which the main objective is to increase farm productivity and profit through efficient use of farm resources. The differences between these two approaches lie in the following.

a) Crop-production technology. The single-commodity approach is only concerned with one crop whereas multiple cropping involves several crops. Thus, in the single-commodity approach, all the recommended practices, i.e., fertilization, pest control, and variety, are directed solely to a single crop whereas in multiple cropping the recommended technology specifies the cropping pattern as well as the specific practices for all the component crops involved in the cropping pattern.

b) Extension technician. In the single-commodity approach, the responsibility of an extension technician is limited solely to one crop, and he is expected to assist only those farmers who grow that crop. A farmer who grows other crops as well may have to seek the assistance of other technicians for problems related to them. In contrast, in the multiple-cropping approach, the technician is mandated to assist in increasing the farmer's productivity by helping him select the best cropping pattern to follow and the best production practices to use for each of the crops included in the selected pattern. Clearly, the multiple-cropping technician covers a much broader area of technical competence and, therefore, must be given appropriate preparation to handle this more difficult assignment.

c) Credit facility. In the single-commodity approach, credit is made available for only one crop to the exclusion of all others. Thus, in a rice-production program a farmer is eligible to borrow only if he grows rice and only for that portion of his farm planted to rice. Also, he must repay his loan soon after the rice is harvested, a requirement that prevents him from using the loan to finance the production of those crops which he may grow after rice. In contrast, the lending policy in the multiple-cropping approach is to finance the farmer in his effort to produce more from his farm regardless of the crops being grown. On credit facilities, for example, production loans in a multiple-cropping production program are generally granted to finance crop production for the whole year. Loan maturity is for one year and the proceeds from a previous crop can be used to finance the succeeding ones.

d) Suitable area of application. The single-commodity approach is suited to areas where only one crop is grown predominantly, and where crop diversification within a farm is not appreciable such as in irrigated areas where submerged soils predominate. The multiple-cropping approach, on the other hand, is suited to areas in which many different types of crops are grown, even within one farm, such as under upland culture, where the land is tilled dry and many different types of upland crop can be grown either by intercropping or sequential cropping.

Crop-production programs in the Philippines and in other Asian countries have, in the last decade, primarily followed the single-commodity approach. Typical examples are the rice-production programs of the Philippines (Carangal 1978) and of Indonesia (Birowo 1975a). The single-commodity approach is attractive for two reasons. First, the improved technology for a single crop is much easier to transmit to farmers as compared to that for several crops in multiple cropping. Clearly, the recommended practice for a very familiar crop like rice is much easier to learn, both by the extension technicians and by the farmers themselves. Also, difficult decisions about which crop to grow are non-existent in a single-commodity program. Secondly, in the single-commodity approach, the limited resources of the government can be concentrated on a single crop, thus maximizing the chance of success of the program. With the rice crisis in 1972, the Philippine government was able to mobilize both its personnel and its financial resources to increase rice production within the shortest possible time through the Masagana 99 Rice-Production Program.

A very concentrated and very selective production program cannot, however, persist permanently. The very feature that makes it attractive -- simplicity and selectivity -- is also its major weakness. A country's resources cannot be continuously used to subsidize only a small sector of the farm communities to produce a special product. Only a crisis situation can justify such a special program, the success of which would solve the crisis and would automatically remove the justification for its existence.

There are, now, several compelling reasons for including several commodities in a national production program. First, the sense of equity among the farming sectors dictates that the government's subsidy will not forever be concentrated on only one sector. Secondly, farm income in the narrow sense, and rural development in the wider context, cannot continue to ride on the increased productivity of only one commodity, even one as important as rice. Here lies the difficulty of continuously relying on single-commodity programs which cannot be expected to serve many commodities simultaneously. With the proliferation of single-commodity programs, each with its own administrative set-up, problems of overlapping coverage and high administrative overheads are inevitable. The multiple-cropping approach, which can integrate the various single-commodity programs offers a promising alternative.

The Single-Commodity Approach: A Case Study of the Masagana 99 Rice-Production Program

Although the Philippines achieved self-sufficiency in rice as early as 1968, a series of drawbacks due to floods and droughts between 1970 and 1973 resulted in a decline in rice production in the face of rapidly increasing consumption. As a result, the Philippines had to import large quantities of rice during a period when rice prices were high, making the importation extremely costly for the country. With this crisis, the Philippine government launched, in 1973, a national production program, code-named Masagana 99[5], the main objective of which was to reduce rice importation and to achieve self-sufficiency in the shortest possible time (Carangal 1978).

Strategy for Implementation

The strategy for rapidly increasing rice production in the Philippines through the Masagana 99 Rice Production Program consists of seven main components.

Favourable Target Areas. Two guidelines were followed in selecting the initial target areas. First, to facilitate the management of the program, priority was given to provinces with large rice-growing areas. Thus, during the first year of the program, less than half of the provinces in the country participated in the program. Secondly, priority was given to areas with irrigation since they were perceived to have the best potential for increased rice production (Table 14.1).

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[5] Masagana is a Filipino word meaning "bountiful" and the figure 99 quantifies the goal of the program which is to increase rice yield to 99 cavans/ha (4.4 t/ha).

Improved Production Technology. The package of technology that was recommended to substantially increase the rice yields in the target areas revolved around the use of high-yielding varieties that respond favourably to improved management practices. These improvements in management consisted mainly of the application of more fertilizer and the use of better practices in pest control. The recommended package of technology was tested in 1972 in several pilot communities in Central Luzon, covering an area of 2600 ha. The average yield among the closely supervised farms in these pilot communities exceeded 4 t/ha, whereas the surrounding farms had yields of 2 to 3 t/ha (Chandler 1979).

Trained Extension Technicians. The extension technicians were the backbone of the program. They personally transmitted the recommended technology to the farmers, facilitated the lending and the collection of production loans, and helped farmers to sell their produce. Before being fielded to their respective areas of assignment, all technicians went through a rigorous training program which updated them on the new production techniques, the new credit scheme, and other aspects of the program. The initial plan was for each extension technician to supervise 150 farmers in this area of assignment.

Availability of Credit. To finance the additional production expenditures required by the new technology, farmers were eligible to borrow

Table 14.1. Target area, number of technicians and farmer cooperators and loans granted and repaid in the Masagana 99 Rice Production Program, 1973 to 1976

Item	Wet season			Dry season[2]		
	1973	1974	1975	1973	1974	1975
Target area (1000 ha)	600	909	1140	350	580	645
Irrigated area (%)	83	74	74	86	97	82
Area harvested (1000 ha)	682	926	1044	380	695	639
Average yield (t/ha)	3.32	3.00	3.69	3.47	3.75	3.44
Extension technician (No.)	3133	3480	4202	3095	3711	3858
Farmer cooperators (No. x 1000)	566	772	707	338	476	492
Ratio of farmers to one technician	181	222	168	109	128	128
Loans granted (million $)	49.2	95.5	76.2	30.8	76.3	29.1
Loan repayment (%)[3]	93	81	64	92	76	67

[1] From 1 May to 31 October.
[2] From 1 November to 30 April.
[3] As of 30 September 1976.
Adapted from Quisumbing et al. (1976).

from local banks up to $160 per hectare at an interest rate of 12% per year, which was less than one-fifth of the prevailing rate. To take advantage of this facility, the farmer, with the help of the extension technician, had to prepare a farm plan and the corresponding budget requirement, to agree to follow all the recommended practices, and to promise to repay the loan from the produce of his crop. To motivate local banks to participate in the program, the Central Bank of the Philippines provided them with two attractive incentives: a 75% guarantee on all production loans made in connection with the program; and a soft loan with an interest rate of 2% per year.

Assured Input and Output Market. With the rapid adoption by farmers of the recommended technology, a substantial increase was expected in both the demand for farm inputs and the amount of marketable farm surplus. In terms of inputs, private companies were encouraged to improve their distribution network to ensure the availability of all inputs where and when they were needed by farmers. To avoid the decline of prices due to the expected increase in farm output, the government legislated a minimum price for rice. The National Grain Authority was established, the main function of which was to purchase rice whenever its price was lower than the legislated minimum.

Effective Management. With more than 30 public and private institutions directly involved in the implementation of the Masagana 99 Rice Production Program, a key ingredient in the success of the program was a well-defined mechanism for coordinating the activities of all participating units. This was the primary function of the newly created National Food and Agriculture Council (NFAC), chaired by the Minister of Agriculture with the heads of 31 participating agencies as members. Three central committees were created to assist the NFAC (Figure 14.1): the National Management Committee, which acts as the executive committee of the NFAC, composed of an NFAC Executive Director (chairman) and 18 representatives from government and private agencies; a Technical Committee composed of researchers from UPLB and IRRI to review periodically the recommended production technologies; and an Information Committee to take charge of the massive information campaign. Similar coordinating committees were set up at the regional, provincial, and municipal levels, to bring together the leaders of the private sector and public officials, who could lend key support to the program.

Efficient Monitoring. Each extension technician recorded, on a monthly basis, the following data for each farmer he supervised: area planted, area harvested, production loans approved, amount released, and amount paid. The data were summarized and the over-all summary for the whole country was usually completed 15 days after the end of each month.

Also, an agricultural program evaluation service was created by NFAC to audit regularly the implementation of approved plans and programs. This unit also conducted regular field inspections, verified the accuracy of the reports coming from the field, and made periodic reports to the national management committee.

Results and Accomplishments

The important indicators of the performance of the Masagana 99

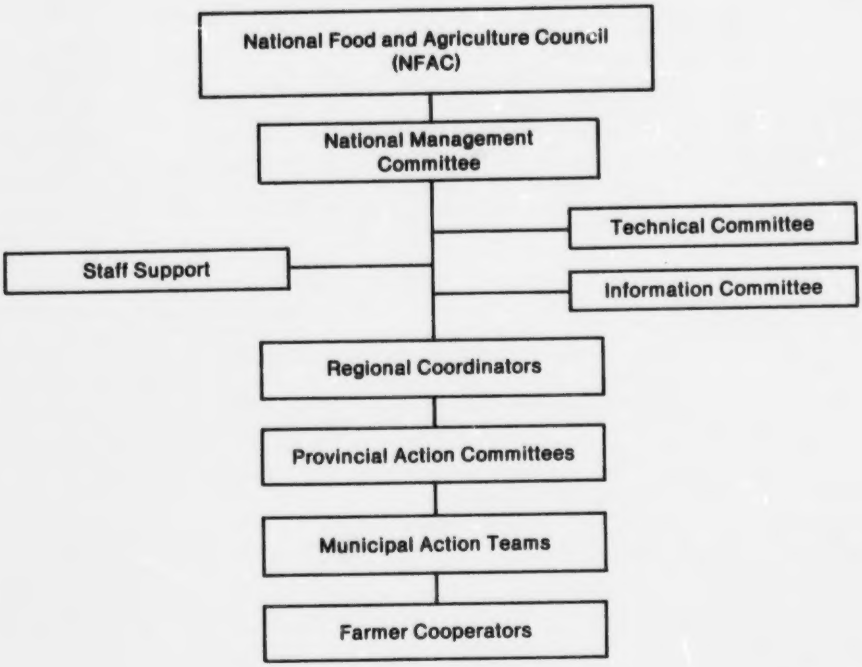
National Food and Agriculture Council
(NFAC)
National Management Committee
Technical Committee
Staff Support
Information Committee
Regional Coordinators
Provincial Action Committees
Municipal Action Teams
Farmer Cooperators

Figure 14.1. Organizational chart showing the organization and management of the Masagana 99 Rice-Production Program.

Rice-Production Program in the first three years (1973 to 1975) are summarized.

a) Productivity. During the first three years, a cumulative harvest area of about 4.4 million ha was actually supervised by the program, an area that is about three percent more than the target (see Table 14.1). Average rice yields during the first six cropping seasons ranged from 3.00 to 3.69 t/ha. These yields compared favourably with the national average which was less than 2.0 t/ha.

b) Amount borrowed and repaid. During the first three years, a total of $357 million was borrowed by farmers in the program (see Table 14.1). The largest amount of loans was released during the second year, but poor harvest during that year resulted in a significant increase in the number of farmers who defaulted in repaying their loans. Because defaulting farmers were disqualified from taking new loans, there was a significant decrease in the amount borrowed in the succeeding year (see Table 14.1).

c) Others. Two other important experiences of the program are worth mentioning. First is the fertilizer shortage. The chemical companies had underestimated the farmers' response to the program and were not ready for the very substantial increase in the demand for farm inputs, which resulted in a shortage of agricultural chemicals, particularly fertilizers. This problem was partly solved by importation. However, because the price of fertilizer in the world market was very high during that time, the program had to subsidize the price of fertilizers used in the target areas in avoid dampening farmers enthusiasm in following the recommended levels.

The second experience is that gained from the ratio of farmers to each extension technician. The initial plan of the program was to have one technician supervise 150 farmers. Enthusiastic response from farmers in the target areas, however, resulted in a ratio of 1:184 in the wet season of 1973 and 1:222 in the next year. With those very high ratios, most technicians were not able to visit their farmers often enough. This lack of contact between each technician and the farmers was also hypothesized to be one of the important contributors to the poor repayment of production loans in the second year. Starting from the wet season of 1975, however, more technicians were hired and the number of farmers for each technician dropped from 222 to 168, which was closer to the originally planned ratio of 1:150.

The Multiple-Cropping Approach: A Case Study of the National Multiple-Cropping Production Program

With the success of the Masagana 99 Rice-Production Program and apparent self-sufficiency in rice in the country, other single-commodity production programs with very similar strategies were initiated, such as the Masaganang Maisan for corn (NFAC 1975) and the Gulayan sa Kalusugan for vegetables (NFAC 1976). However, because each single-commodity production program must have its own personnel and its own administrative overheads, as more and more commodities were included, the organization became less efficient and the cost became too high. Thus, in 1976, the Ministry of Agriculture of the Philippines initiated the integration of several existing single-commodity production programs into a single program following the multiple-cropping approach.

Strategy for Implementation

The National Multiple-Cropping Production Program basically integrated three existing single-commodity programs, the Masagana 99 for rice, the Masaganang Maisan for corn, and the Gulayan sa Kalusugan for vegetables. Integration was introduced through crop-production technology which emphasized the intensification of land use through multiple cropping, supervised credit which covered all crops grown over a period of one year instead of a specific focus on a single crop, and extension technicians with their area of responsibility changed from a single crop to all crops grown by the farmers.

As in the Masagana 99 Rice-Production Program, the National Multiple-Cropping Production Program had several major components.

Favourable Target Area. Based on the performance of the existing single-commodity production programs, the target area of the national multiple-cropping program was selected on the basis of good market, good technicians, and satisfactory loan repayments. Also, the target area must be contiguous and large enough such that the institutional problems related to the process of integration could be evaluated. On these bases, the whole province of Pampanga, with a cultivated area of about 60,000 ha, was selected as the initial target area.

Improved Production Technology. The production technologies employed were the rice-based (Chapter 2) and the annual upland crop (Chapter 3) multiple-cropping technologies. All the component technologies recommended for rice by the Masagana 99 Rice-Production Program (NFAC 1974), for corn by the Masaganang Maisan Program (NFAC 1975), and for vegetables by the Gulayan sa Kalusugan Program (NFAC 1976) were followed. An added emphasis, based on the multiple-cropping approach, was to motivate farmers to plant early and to increase the number of crops that could be grown and harvested in the same piece of land within a 12-month period.

Trained Extension Technicians. All extension technicians in the target area of the three single-commodity production programs -- the Masagana 99, the Masaganang Maisan, and the Gulayan sa Kalusugan programs -- were converted to multiple-cropping technicians. Of the technicians, 92% were BSc degree holders and 57% had more than five years of experience (Table 14.2). Each technician was responsible for advising his farmers not only for a single crop but also for all annual crops grown on their farms. With this assignment scheme, a farmer had to deal with only one

Table 14.2. Profile of the extension technicians employed in the National Multiple Cropping Production Program

Item	Amount
Technicians (No.)	189
Female (%)	24
BSc degree holder (%):	92
Less than 1 yr experience (%)	15
1-5 yr experience (%)	28
More than 5 yr experience (%)	57
No. of barrios per technician:	
Before program[1]	3.79
After program[2]	1.05
No. of farmers per technician:	
Before program[1]	133
After program[2]	80

[1] Before initiating the National Multiple Cropping Production Program in which technicians were assigned to separate single commodity programs.

[2] After reassignment based on the multiple-cropping approach in which technicians were assigned to assist farmers with all crops grown on the farm.

Source: Gomez (1978).

technician regardless of the diversity of crops grown. Consequently, the number of farmers that one technician supervised was reduced from 133 under the single-commodity approach to 80 in the multiple-cropping approach.

Available Credit. Although the existing commodity-oriented lending scheme was allowed to continue, the Integrated Agricultural Financing Scheme (IAF) was encouraged in all project areas. Under the IAF, farmer borrowers were granted a credit line for one year for the implementation of a duly-approved cropping pattern. A farmer, therefore, borrowed only once a year for all the crops he expected to grow.

To familiarize the rural bankers with their roles in this IAF scheme, the top administrators of each rural bank in the target area were requested to attend a one-week seminar on the multiple-cropping technology and on the IAF.

Assured Market. One of the most important requirements for the success of a multiple-cropping production program is to ensure a market for the additional farm products. To do this, two existing government agencies, the National Grains Authority (NGA) and the Food Terminal Market (FTI), the main function of which is to improve the marketing of agricultural products, were asked by the program to increase the volume of their purchases in the target areas.

Effective Management. The organization and management of the National Multiple-Cropping Production Program were essentially built on the existing structures developed by the Masagana 99 Rice-Production Program (see Figure 14.1). It was coordinated by NFAC at the national level. At the provincial level, the existing provincial coordinators for the Masagana 99, the Masaganang Maisan, and the Gulayan sa Kalusugan programs informally pooled their resources to provide coordination for the national program.

Effective Monitoring. An efficient reporting system capable of monitoring the status of the program at any given time is very essential to any national production program. For the National Multiple-Cropping Production Program, three activities were undertaken in this regard. First, each technician was required to list the names of his farmers, the area of their farms, their tenure status, and their proposed cropping patterns. Secondly, each technician was required to record the monthly activities of his farmers in terms of crops planted, volume harvested, amount borrowed, and amount repaid. Thirdly, from the list of farmers prepared by the technician, a 10% random sample was interviewed by the project staff to countercheck the technician's report and to serve as samples for the periodic evaluation of farm productivity.

Results and Accomplishments

The performance of the National Multiple-Cropping Production Program for the crop year 1976-1977, the first year of its implementation, is indicated by the following results.

a) Productivity. Only 73% of the target area was actually planted (Table 14.3) because the target province was flooded during the

Table 14.3. Target area, planted area, and estimated yield, by crop, in the National Multiple Cropping Production Program, 1976 to 1977

Crop	Target area (ha)	Actual area planted (ha)	Yield (t/ha)
Rice	83,565	70,170	2.80
Corn	6686	655	2.14
Other grain crops	5771	1153	0.93
Non-grain crops	5528	2127	1.70
Total	101,550	74,105	-

Source: Gomez (1978).

early monsoon months and the planting date for most of the first crop was delayed. As expected, the two most commonly grown crops were rice and corn. Compared to the country's average of 2.15 t/ha for rice and 0.84 t/ha for corn, the productivity level in the target area during the first year of the program was considered to be fairly high.

b) Amount borrowed and repaid. There were 5517 farmers who used the credit facility of the program. The total amount released to these farmer-borrowers was \$1.35 million of a possible \$1.66 million approved, of which only 56% was repaid by the end of the crop year. Because the program covered essentially the same farmers who were participants in the previous single-commodity production program, their previous credit problems were carried over to the present multiple-cropping production program. Also, the rate of repayment in the Masagana 99 Rice-Production Program, the most dominant single-commodity program, had gone down to as low as 35% at that time (Chandler 1979).

c) Administration. The task of organizing one set of administrative officers from out of the three independent single-commodity production programs, each with its own set of administrators, was difficult. On one hand, integration meant a reduction in the number of officers, and on the other hand, it is difficult to change or modify the status of each of the provincial officers in each of the previous single-commodity programs, because all had formal appointments from the national government that carried with them financial incentives. Consequently, the administrative integration required by the National Multiple-Cropping Production Program could only be implemented on an informal basis, resulting in some confusion on the working relationship among the provincial administrators and the municipal officers.

PART IV

CONCLUSIONS

CHAPTER 15: SUMMARY

Multiple cropping, or the practice of growing several crops on the same piece of land, is an ancient strategy for crop production in the humid tropics. It is used by subsistence farmers to increase the diversity of their product and the stability of their annual farm output. With the rapid increase in farm population and the dwindling supply of new lands for cultivation, however, multiple cropping is being looked upon as an excellent strategy for intensifying land use and for absorbing excess labour. With these new objectives, the traditional multiple-cropping strategies have to be modified and new ones developed. This book summarizes the new production technologies derived from results of research in multiple cropping in Asia in the 1970s, outlines a research approach for developing and utilizing new multiple-cropping technologies, and describes the Philippine experience in accelerating the adoption by farmers of multiple-cropping techniques.

Production Technology

Development of multiple-cropping production technologies in the humid tropics of Asia has focused on the following four major production areas: first, the lowland rice areas that are cultivated under submerged and puddled soils; secondly, the upland annual crops areas that are characterized by well-aerated and unsubmerged soils; thirdly, the upland perennial crop areas that are dominated by permanent trees; and fourthly, the hilly lands whose topography is dominated by slopes exceeding 15%.

Lowland Rice Areas

Rice is the most widely grown crop in Asia because of its adaptability to heavy rainfall, its tolerance to water-logging and strong winds, its ease in storage and marketing, and its important role as a food staple in the region. Intensification of land use in the lowland rice areas is enhanced by the development of varieties of upland crops that are uniquely suited to the environmental stress of the rice paddies, of rice varieties with short growth duration, of new cultural practices for lowland rice, and of new cultural practices for growing upland crops in the rice paddy.

Sequential cropping patterns involving rice and annual upland crops are most suited in the rice paddies. The most commonly used ones are: rice - rice, rice - rice - rice, rice - upland crop, upland crop - rice, rice - rice - upland crop, and upland crop - rice - upland crop.

In selecting the appropriate cropping pattern to grow in a particular farm, the important factors to consider are water availability, soil texture, topography, and market accessibility.

Upland Annual Crop Areas

Upland areas are characterized by gently sloping landscape, dryland seedbed preparation, and absence of levees and standing water. Annual crops are commonly grown in these areas because of their short growth duration and morphological diversity. The traditional cropping pattern is characterized by crop diversity to satisfy the food requirements of the family, minimum input of commercial farm chemicals, and maximum stability through the use of varieties that are tolerant to environmental stresses.

Varietal improvement for short growth duration, drought tolerance, and shade tolerance, together with the improvement of cultural and management practices in intercropping, are the most active research areas in multiple cropping with upland annual crops.

As in the lowland rice areas, the major consideration in selecting the appropriate cropping patterns in upland annual crop areas are rainfall, soil characteristics, and market accessibility.

Upland Perennial Crop Areas

Perennial crops occupy an important place in the world agriculture because of their high income potential, low input requirement, and long periods of productivity. In areas supporting perennial crops, intercropping is commonly practiced because of the wide distance of planting required to accommodate the large canopy of the perennial main crop, the need to provide supplemental income for the farm household during the long unproductive seedling stage of the perennial main crop, and the existence of a wide choice of crop species that could adapt to the shaded environment under the perennial main crop. The traditional cropping patterns in these areas can be grouped into two categories: the subsistence farm in which a small portion of the farm is planted to a highly diverse mixture of perennial crop species and the large plantation in which a single species is grown.

The stage of growth of the perennial main crop is a major determinant of the crops that can be grown below its canopy. At the pre-flowering and late senescence stages, when shading is minimal, the dominant intercrops are the annual grain crops, which are high yielding and fast maturing and whose products are easy to market. During the reproductive stage when shading is maximal, the shade-tolerant perennials such as banana, cacao, and coffee are the dominant intercrops.

Hilly Lands

With the increasing population pressure and the non-availability of flat areas, the hilly lands, which occupy more than 30% of the land mass in the humid tropics of Asia, constitute an important and challenging potential for agricultural expansion. Hilly lands, however, are fragile and prone to rapid deterioration under poor management. Thus, cropping patterns that are suited to hilly lands are those that balance the twin objectives of high productivity and soil conservation.

Aside from the traditional slash-and-burn method of cultivating hilly areas, new cropping patterns that have shown potential are fruit-tree farming, industrial forest plantation, and intercropping with perennial legumes. Because of the need for continuous income to support the family, the small farmer of the hilly lands will probably choose to grow some annuals in spite of their poor potential for soil conservation.

In terms of soil conservation, slope, rainfall, and soil properties are the three major determinants of cropping pattern in hilly lands. The steeper the slope, the higher the rainfall, and the poorer the soil structure, the higher is the potential for soil erosion and deterioration. Crops with dense canopies whose tillage requirements are minimal and that have long life cycles are more effective soil conservers relative to the short-cycled and small-statured annual crops.

Research Methodology

With the expected interaction among component crops in a cropping pattern, multiple-cropping research is primarily concerned with the evaluation of crop-production strategies that are packaged at the cropping pattern level rather than at the single crop level. Consequently, multiple-cropping research is characterized by a large number of factors to be tested, plot techniques that vary with crops, and productivity that needs to be measured both biologically and economically.

Experiments in farmers' fields are of major importance in multiple-cropping research where the interaction between technology and environment is expected to be large. Compared to the research station, however, farmers' fields have the four less favourable features: first, lack of experimental facilities; secondly, large variation among farms; thirdly, non-uniformity of fields within farm; and fourthly, poor accessibility. Consequently, experiments in farmers' fields are expected to have a lower degree of precision and a higher chance of failure relative to those conducted in research stations.

Technology Generation Experiments

Technology generation experiments are primarily designed to develop new techniques that can maximize biological yield or minimize production cost. In these experiments, many new techniques are usually evaluated and, although many are expected to fail, one or two superior ones may be discovered.

Research methods for technology generation must be able to evaluate, simultaneously, a large number of factors without unduly enlarging the size of the experiment. A useful technique for doing this is to divide the experiment into two phases: in Phase I, many factors, each with as few levels as possible, are evaluated simultaneously; and in Phase II, several trials, each with fewer factors but more levels per factor, are evaluated separately. In Phase II, the factors that are tested together in the same trial are those that were shown in Phase I to have large interactions among themselves. For Phase I, two experimental designs that are useful in reducing the size of the experiment are the fractional factorial design in which only a fraction of the treatments is tested and the continuous variable design in which small plots are used.

Although farmers' fields have poorer experimental facilities, are more heterogeneous, and are less accessible to researchers than the research station, their use as test sites for technology generation experiment has several attractive features. The three most important are: first, it is a convenient way to sample a wide array of environments that are not available in the research station; secondly, it provides an opportunity for researchers to be directly exposed to the farmers' needs and constraints; and thirdly, the experimental results are expected to be more realistic and more attuned to the farmers' needs and capabilities. Although the experimental procedure for an on-farm technology-generation experiment closely resembles the traditional procedure for a research station trial, some modifications and additions are needed to cope with the distinctive features of using a farmer's field as the test site, i.e., reduction of treatments to be tested and characterization of the physical and biological environment in each test farm.

A useful research tool for generating new production technologies in multiple cropping is the use of computer simulation techniques. These techniques involve the development of a model that can predict crop productivity over a wide range of growing conditions, the verification of the validity of the model by comparing its predicted performance with actual field performance, and the selection of the production strategy that can best utilize the limited resources of a given farm. The two major advantages of computer simulation in multiple-cropping research are: first, there is practically no limit to the number of factors or their levels that can be tested; and secondly, the time and cost required are much less than that for field experiments. In spite of these attractive features, however, computer simulation has not been widely used in the humid tropics of Asia because of the lack of computer facilities (both hardware and software) and of the data for model development and verification.

Technology-Verification Experiments

Technology-verification experiments are designed to verify the superiority of a new production technology over the existing practice of the farmer under farm growing conditions. The yield constraints approach, originally designed for technology verification in rice, has been adopted for use in multiple cropping. The approach uses controlled experiments and farm surveys to measure the biophysical and socioeconomic constraints to farmers' adoption of new production technologies. For the controlled experiments, two types of treatment combinations are commonly used: the supplemental set with only two treatments (the new technology and the farmer's practice) and the mini-factorial set in which the number of treatments is two more than the number of test factors.

The number of test farms to be used for an on-farm technology verification experiment depends upon the magnitude of the variation among farms, the precision desired, and the resources available. A good indicator of the variability among farms is the diversity of cropping patterns existing in a target area. In general, the total number of test farms for a target area should be ten times the number of dominant cropping patterns.

Data requirement in experiments for technology verification is less detailed compared to that for technology generation. Many agronomic traits and yield components need not be recorded. In each test farm, however, grain yield must be measured not only on all experimental plots but also on an adjacent area managed by the farmer to ensure that the farmer's practice has been accurately simulated. Data analysis is designed to measure the total yield gap (i.e., yield differences between the farmer's practice and the new technology), the contribution of each test factor to the yield gap, and the added costs and returns of the new technology and of each test factor.

A combined experiment for technology generation and technology verification can be designed to fine tune some specific components of the new technology at the same time that the whole package of technology is being verified. In the combined trial, however, the requirement of technology verification -- either in terms of selection of test farms, experimental design, farmer's participation, or data collection -- should first be satisfied before considering the additional requirements of technology generation.

Farm Survey

Farm survey is an ideal complement to field experiments for technology verification for the following three reasons: first, many socioeconomic factors that can not be measured in field experiments are easily measured through a farm survey; secondly, because its cost per farm is less than that for field experiment, it can be done in a relatively larger number of farms and is, thus, ideal for widening the coverage of the field experiments; and thirdly, farm survey can gather information about the past activities that may be useful as the basis for designing the new package of technology for verification.

Two types of farm surveys are required for technology verification: the pre-design survey, which is conducted before the field experiments are established, and the follow-up survey, which is conducted after the field experiments are completed.

The pre-design survey aims at gathering information on the farmers' existing practices, their production, and the major constraints to increased productivity. Such information is needed in the design of the new technology and in the selection of the test farms to be used for technology-verification trials. The number of sample farms required for the pre-design survey depends upon the diversity of cropping patterns in the target area. At least 40 sample farms are needed for each dominant cropping pattern; or a total of 200 sample farms if there is no previous knowledge on the existing cropping patterns in the target area. Based on the components of the farmers' practices that are suspected to constrain farm productivity, a new package of production technology is designed by incorporating new component technologies that have been shown experimentally to remedy the identified farm constraints.

The follow-up survey is designed to determine the potential constraints to farmers' adoption of the new technology and the institutions required to accelerate farmers' adoption of the new and more productive technology.

Varietal Improvement

There are two alternative approaches in designing a varietal improvement program. First, on the assumption that good varieties perform well over a wide range of environments, the selection of the best genotypes can be done in a single environment. Second, on the assumption that different genotypes differ significantly in their ability to utilize different environmental resources, selection should be conducted in several environments simultaneously. The primary basis for selecting a specific approach is the magnitude of the interaction between genotype and environment. When the interaction between genotype and environment is large enough to cause substantial changes in the rankings among breeding lines that are grown in different environments, the strategy to use is one where the multi-environment selection is introduced in the early stages of the breeding program.

For multiple cropping, differences among environments in which a given crop species is grown are expected to be large and, consequently, the interaction between genotype and environment is also expected to be large. Data from several studies confirmed the expected large interaction between genotype and environment under multiple-cropping environments. Thus, for multiple cropping, multi-location selection must be initiated at least at the replicated-trial stage and, in some cases, even as early as the selection of the parents.

Research Strategy

A research strategy is an allocation of research resources into specific research activities to maximize the efficiency of the research. With the broad coverage of multiple-cropping research, the development of an appropriate research strategy is essential in clarifying the research objectives and the specific activities that significantly contribute to the attainment of the objectives.

The efficiency of research is defined as the rate of increase in farm productivity per unit of resource devoted to research. Considering that the National Agricultural Research Centres (NARC) and the International Agricultural Research Centres (IARC) are the primary research resources for conducting research in multiple cropping in Asia, the efficiency of conducting various types of research was estimated and the following research strategy is suggested.

First, the NARCs immediately increase their investment on technology-verification research because the return for this type of research is high and the technical requirement is within their existing capabilities.

Second, the IARCs concentrate their efforts on technology-generation research because these activities require highly trained personnel that is more easily available in the international centers.

Third, the NARCs and the IARCs should cooperate in the conduct of environmental classification research, with the former supplying the needed data from field tests in many diverse environments and the latter the expertise for analyzing and rationalizing the resulting data.

Philippine Experience in Technology Verification and Dissemination

For most of the developing countries in the humid tropics of Asia, the high levels of productivity shown to be possible in research stations reveal an attractive potential for increasing the low average farm yields. To realize this potential, however, specific programs must be designed to remove the obstacles to farmers' adoption of new and more productive production technologies and, consequently, hasten the transfer of technology from research station to actual farms. These programs can be classified into three groups: technology verification, pilot production, and national production programs.

Technology Verification

Results of technology-verification trials in rice, corn, and multiple cropping in the Philippines have shown substantial yield differences between the new technology and the farmers' existing practices. In all cases, however, some of the components of the new technology were not useful in improving farm yields and should, therefore, be excluded from the final packaging of technology to be recommended for farmers' adoption.

To systematically verify the applicability, to the actual farm conditions, of the newly developed production technologies, a national research network for technology verification was initiated in the Philippines in 1980. This network was a joint responsibility of the research and extension communities, with both organizations contributing jointly to its personnel and administrative requirements. The main function of the network was to package multiple-cropping technologies that would be tested in farmers' fields; and to develop, based on the results of these trials, a new package of technology that would be recommended for adoption by farmers.

Pilot Production Program

The superiority of a new production technology over the farmers' practices does not automatically guarantee its widespread adoption. This is especially so for multiple-cropping technologies whose adoption usually requires the cultivation of new crops, use of additional resources, and timely implementation of required practices.

Pilot-production programs are designed to evaluate the performance of the newly recommended technologies in a few communities to determine the institutional and social requirements for their rapid adoption, the benefits that farmers derive from the adoption, and the major constraints to the adoption.

Experience on two pilot production programs in the Philippines involving the intensification of land use in lowland rice paddies indicated that: first, substantial improvements in land productivity and farm income can be achieved with the adoption of the recommended multiple-cropping technologies; secondly, improved nutrition usually accompanies improved productivity; and thirdly, available credit and accessible production technicians are essential in accelerating farmers' adoption of multiple-cropping production technologies.

National Production Programs

There are two approaches to the establishment of national crop production programs: first, the single commodity approach, in which the main objective is to increase production of a specific commodity; and the multiple-cropping approach, in which the main objective is to increase farm productivity and profit through efficient use of farm resources. Four important features distinguish the single-commodity approach from the multiple-cropping approach:

a) the single-commodity approach is concerned with only one crop whereas the multiple-cropping approach involves many crops;
b) the single-commodity approach deploys extension technicians on a given crop whereas the multiple-cropping approach assigns technicians to a given area;
c) in the single-commodity approach, credit is granted to a specific crop for one planting season but, in the multiple-cropping approach, credit is granted to a farmer to finance several crops that are planted over a period of one year; and
d) the single-commodity approach is suited to areas where monocrop agriculture predominates whereas the multiple-cropping approach is suited to areas with diversified agriculture.

In the last decade, the Philippines as well as other developing countries of Asia have essentially followed the single-commodity approach in their national production programs. This is typified by the rice-production programs of the Philippines and Indonesia. As more single-commodity production programs are initiated, however, problems of overlapping coverage and high administrative overhead costs are encountered. The multiple-cropping approach, which integrates the various single-commodity programs into a single program, offers a promising alternative. This is illustrated by the experience of the Philippines in implementing two production programs: the Masagana 99 rice-production program corresponding to the single commodity approach and the multiple-cropping production program corresponding to the multiple-cropping approach.

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